THE

ELEMENTS

OF

Sir ISAAC NEWTON's

PHILOSOPHY.

By Mr. VOLTAIRE.

Translated from the FRENCH.

Revised and Corrected

By *JOHN HANNA*, M. A.

Teacher of the Mathematicks.

With Explication of some Words in Alphabetical
Order.

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*Pulchre sibi disputare videntur, cum quod evertere
non possunt, tanquam ridiculum contemnunt.*
Horroccius.

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M. VOLTAIRE

TO THE

MARCHIONESS du CH**.

IMMORTAL Emily, vaſt, pow'rful Mind,
Pallas of *France*, and Glory of thy Kind,
Surpaſſing Age, ev'n in thy Bloom of
    Youth,
The Pupil, Friend, of *Newton*, and of Truth.
Thy Fires tranſpierce me, and thy Charms
    controul;   5
I feel the Force, the Brightneſs of thy Soul!
To Thee attracted, I renounce the Bays
Sought on the Stage, while yet I liv'd on
    Praiſe.
My Wit, corrected, roves not as before,
Of vain Applauſe, idolatrous no more!   10
  Let Earth-born *Rufus* with Reſentment
    rave,
And drag his ſenſeleſs Fury to the Grave.
In Rhyme ſtill ſtraining, coldly to encloſe
Some trivial Thought, that would depreciate
    Proſe,

DEDICATION.

15   That harmleſs Thunder let him hurl at me,
Which firſt his Rage for others might decree.
To blaſt my Fame let Pedant *Zoilus* ſeek,
And ſpread unmeaning Malice once a Week.
With me their Envy withers in the Bud ;

20   I ſee no Tracts imprinted in the Mud.

      Philoſophy, all-charming, pow'rful Queen,
Lifts the wiſe Mind above corroding Spleen,
Happy on high, where *Newton* now remains,
Knows He on Earth if Enmity yet reigns?

25   Not more than He my Enemies I know,
While Truth auguſt invites me from below.

      Already ſee ! ſhe opes the Gate of Day!
The Liſts I enter, and purſue my Way !
The maſſy Whirlpools, heaving ſtill for Place,

30   Heap'd without Rule, and moving without
       Space,
Thoſe learned Phantoms vaniſh from my
       Sight,
And Day comes on me with her genuine Light!
That vaſt Expanſe, of Being the Abode,
Space, which contains th' Infinity of God,

35   Sees in her Breaſt this bounded Syſtem move
Of Planets, Worlds, beneath us and above,
Whoſe whole Extent, ſo wondrous to our Senſe,
Is but a Point, an Atom in th' Immenſe.

                    Go

God speaks, and Chaos at his Voice subsides;
In various Orbs the mighty Mass divides :   40
At once they gravitate, they strive to fall,
One Center seeking, which attracts them all.
That Soul of Nature, that all-moving Spring,
Lay long conceal'd, an unregarded Thing ;
'Till *Newton*'s Compass, moving thro' the   45
     Space
Measures all Matter, all discover'd Place;
Finds Motion's Cause, Philosophy unleavens,
Lifts up the Veil, and open'd are the Heavens.
    His learned Hand unfolds the glitt'ring
     Robe,
That clothes yon lucid, animated Globe,   50
Who guides the Seasons, and who rules the
     Day.
Mine Eyes distinguish each emitted Ray.
With Purple, Azure, Emerald, and Rose,
Th' immortal Tissue of his Habit glows.
Each Emanation, in pure Substance, bears   55
The various Colours that all Nature wears :
Those blended Taints illuminate our Eyes,
Give Life to Matter, fill th' expanded Skies.
    Eternal Pow'rs, who, near the King of
     Kings,
Burn with his Fires, and cover with your Wings.   60

       A 3   His

His Throne; O tell us! viewing *Newton's* Plan,
Were you not jealous of that wond'rous Man?
The Sea too hears him. With ſtupendious
    Dance
I ſee the humid Element advance!
65 Tow'rds Heav'n it riſes; Heav'n attracts it
    high:
But central Pow'r, more potent, as more nigh,
Each Effort ſtops: The Sea recoils; it roars;
Sinks in its Bed, and rolls againſt the Shores.

    Ye Comets, dreaded like the Bolts of Jove,
70 In vaſt Ellipſes regularly rove!
Ceaſe with your Motion Mortals to affright:
Remount, deſcend near the great Orb of Light:
Elance your Fires; fly; and, as each appears,
Reſtore the Vigour of exhauſted Spheres!

75   Thou, Siſter of the Sun, who, in the Skies,
Of dazzled Sages mock'd the feeble Eyes
Newton has mark'd the Limits of thy Race:
March on; illumine Night; we know thy
    Place.
    Earth, change thy Form; let the great Law
    of Matter,
80 The Pole depreſſing, elevate th' Equator!
Pole, fix'd to Sight, avoid the frozen Car,
The Conſtellation of the Northern Bear:
                Embrace,

Embrace, in each of thy immenfe Careers,
Almoft two thoufand Centuries of Years *!
  How beautiful thefe Objects! how the Mind   85
Flies to thefe Truths, enlighten'd and refin'd!
Yes, in the Breaft of God, from Matter free,
It hears the Voice of that eternal He.

  Thou, whom that Voice familiarly invites,
Say, ev'n in Youth, the Seafon of Delights,   90
How haft Thou dar'd, in fpite of Cuftom's
    Force,
To move fo boldly, thro' fo vaft a Courfe?
To follow *Newton* in that boundlefs Road,
Where Nature's loft, and ev'ry Thing but God?
  Purfuing Thee, I venture to advance,   95
And bring home Truth, that Wanderer, to
    France.
While *Algaroti* †, fure to pleafe and teach,
Conducts the Stranger to the Latian Beach,
With native Flow'rs adorns the beauteous Maïd,
And *Tyber* wonders at fuch Worth difplay'd;   100

---

* *Almoft two thoufand Centuries.*] Mr. *Voltaire's* Line is

    Deux cens fiecles entiers par delà fix milleans.

  But the Period he is fpeaking of, according to his own
Account of it, confifts of 194000 Years, which is almoft
two thoufand Centuries.

  † *Algaroti.*] A young *Venetian*, who is now printing at
Venice a Treatife on Light, in which he explains Attraction.

I grasp the Compass, and the Out-lines trace,
And with coarse Crayons imitate her Face.
Th' immortal Fair, all simple, noble, grand,
Should I attempt it, my unskilful Hand
105 To Her, as Thee, no Lustre could impart,
Above all Praise, and far above my Art.

14 NO 63

THE
PREFACE.

IT seems to have been the Design of the Author in the following Treatise to give only a Taste of Sir Isaac Newton's natural Philosophy to those who have heard his Works much commended, but had not enough of Mathematical Learning to read them; tho' there are in several Places several curious Things to entertain the more Learned.

The Author himself hath observed several Errors in the French Edition, printed at Amsterdam; and therefore it was necessary in this Edition, which is taken from it, to make several Amendments, tho' perhaps some may be wanting still; particularly in Page 12. Line 10. where it's said the Distance of the Stars is as their apparent Magnitude inversly, some may think it should be the Square of their Distance; but even that would not be true, except

their

their real Magnitudes were all equal, which is scarcely credible; a few others were marked with the Errata, which may be soon helped.

The Reader is at Liberty to pass over the few Remarks at the Bottom of some Pages, tho' they were inserted by one who is neither a rigid Newtonian *nor* Cartesian, *and so no Party Man;* for Amicus Plato, Amicus Aristoteles, sed magis amica veritas. *There are not only the Prejudice of Education, but also Interest, the Estimation of others, and Selfconceit, that give a great Biass to the Judgment, and sometimes* Decipimur specie recti. *This Treatise may serve to rectify the Judgment of those that can bear to read any thing against it.*

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ERRATA.

PAGE 70. *Line* ult. *for* directed *read* deceived.
P. 170. *l.* ult. *for* fufpended *r.* fuperadded.
P. 172. *l.* 9. *for* Eclipfes *r.* Ellipfes.
P. 173. *l.* ult. *for* good *r.* hold good.
P. 144. *l.* 8. *at the Beginning, r.* reflects, *and dele* nothing.
P. 160. *l.* 5. *r.* abfolute Gravity.

TO THE
MARCHIONESS of CH**.

INTRODUCTION.

MADAM,

NEITHER your Title, nor the Philofophy here treated, are imaginary. Your folid Study of many new Truths, and the Fruits of fo meritorious an Application, are what I now offer the Public for your own, and the Glory of your Sex, and for the Improvement of all fuch as defire to cultivate their Reafon, and enjoy without difficulty the Benefit of your Enquiries. Graces and Beauties are not to be expected here. Every Hand is not capable of covering the Thorns of the Sciences with the Flowers of Wit and Fancy; and for my part I ought to make it my fole Endeavour in this Effay to conceive certain Truths aright, and to explain them with Order and Perfpicuity: To attempt to adorn them, were encroaching upon your Province.

B 2   The

The Name of new Philofophy would be no more than the Title of a new Romance, if it implied only the Conjectures of a Modern in oppofition to the Notions of the Ancients. A Philofophy, founded only upon accidental Explications advanced at a venture, would not in ftrictnefs deferve the leaft Examination. For the Methods of arriving at Error are innumerable, whilft there is but one Way that leads to Truth; it is therefore the odds of infinite to one, that a Philofopher, who fupports his Principles only by Hypothefes, will advance nothing but Chimera's. Hence it is, that all the Ancients, who have treated Phyficks without the light of Experiments, have been only the Blind explaining the Nature of Colours to the Blind.

This Tract will not be a compleat Courfe of Phyficks. That were to make it immenfe; a fingle part of Phyficks employing the Lives of many Men, and often letting them die in Uncertainty.

You confine yourfelf in the Study, of which I treat, folely to forming a clear Idea of thofe fubtle and powerful Springs, thofe primary Laws of Nature, difcovered by *New-*

ton;

ton; to examining how far others had gone before him, from whence he set out, and where he stopped. We shall begin like him with Light, which, tho' the most subtle of all Bodies, and that which approaches the nearest to infinitely little, is however the Body of which we know the most. It has been traced in its Motions and Effects; it has even been anatomized and separated into all its possible Parts. Of all Bodies, it is that which most explains the Secrets, and brings us the nearest to the first Springs, of Nature.

We shall endeavour to make these Elements easy and intelligible to those, who know no more of *Newton* and Philosophy than their Name. The Knowledge of Nature is a Good, to which all Men have an equal Right: all are for knowing their Good, which few have Time or Patience to calculate; this *Newton* has done for them. Here we must sometimes content ourselves with the total of those Calculations. A publick Man, a Minister, every day forms a just Idea of the result of Operations not in his own Power to execute; the Eyes of others have seen, the Hands of others have laboured for him, and

enable

enable him by faithful Reports to pafs his
Judgment.   Every Man of Wit will be here
almoft in the fame cafe with this Minifter.

Newton's Philofophy has hitherto feemed
to many as unintelligible as that of the Anci-
ents; but the Darknefs of the *Greeks* proceed-
ed from their having in reality no Light at
all, whilft that of *Newton* arifes from his
Light's being too remote from our Eyes.
He has difcovered Truths; but he has fearch-
ed for, and placed them in an Abyfs, into
which it is neceffary to defcend, in order to
bring them out, and to place them in full
Light.

The Reader will find here all thofe Truths
which tend to eftablifh the new Property of
Matter difcovered by *Newton*. We fhall be
obliged to fpeak of fome Singularities which
occur in the courfe of our Defign; but we
fhall not lofe Sight of our End.

Thofe who defire to inftruct themfelves
more at large, may read the excellent Phy-
ficks of *Gravefande*, *Keil*, *Mufchenbroek* and
Pemberton, and approach to *Newton* by de-
grees.

                              C H A P.

CHAP. I.

What Light is, and in what manner it comes to us.

THE *Greeks*, and after them all the barbarous Nations, who learnt of them to reafon and to err, have faid from Age to Age thro' a long feries of Time; " Light is " an Accident, which Accident is the act of " Tranfparent as Tranfparent; Colours are " what move tranfparent Bodies. Lumi- " nous and coloured Bodies have Qualities " like thofe they excite in us, according to " the Maxim, that nothing can give what it " has not. In fine, Light and Colours are " a mixture of the hot, cold, dry and hu- " mid ; for the humid, dry, cold and hot, " being the Principles of all Things, Colours " muft neceffarily be compofed of them."

This is the abfurd Jargon, which the Profeffors of Ignorance, paid by the Publick, have made human Credulity revere for fo many Ages; which manner of reafoning prevailed almoft in all things down to the t mes of *Galileo* and *Defcartes*. Even long after

them

them the fame Trafh, the Difgrace of human Underftanding, fubfifted in many Schools. I dare aver that human Reafon, fo obfcured, is far below the narrow indeed, but certain, Perceptions, which in Brutes we call Inftinct. Hence we cannot congratulate ourfelves too much on our good Fortune in being born at a Time, and amongft a People, in which, and with whom Mankind begin to open their Eyes, and to enjoy the nobleft Inheritance of Humanity, the Ufe of Reafon.

All the pretended Philofophers therefore having gueft of Nature at a venture thro' the Veil, under which fhe lay concealed, *Def-cartes* at length came, and difcovered a Corner of that great Veil. He faid: Light is a fine and fubtle Matter diffufed univerfally, that ftrikes our Eyes. Colours are Senfations excited in us by God, according to the Motions which tranfmit that Matter to our Organs. Thus far *Defcartes* was in the right, and ought either to have ftopped there, or in advancing, to have taken Experiment for his Guide. But he was poffeffed with the defire of eftablifhing a Syftem. That Paffion had the fame effect on this great Man, as Paffions have

The Fondnefs for eftablifhing a Syftem mifled Defcartes.

have on all Men ; they hurry them beyond their Principles.

He had laid down as the firſt Principle of his Philoſophy, that nothing ſhould be believed without Evidence; and yet, in Contempt of his own Rule, he imagines three Elements formed of pretended Cubes, which he ſuppoſes to have been made by the Creator, and to have been broken to pieces in turning upon themſelves, after they came out of the Hands of God. Theſe three imaginary Elements are, as every body knows,

1. The moſt denſe parts of theſe Cubes; *His Syſtem.* of which groſs Element, according to him, the ſolid Bodies of the Planets, the Seas, and even the Air are compoſed.

2. The imperceptible Duſt, which the breaking to pieces of theſe Dice had produced, and which fills to Infinitude the Spaces of the infinite Univerſe, in which he ſuppoſes no Vacuum, or Void.

3. The Middles of theſe pretended Dice broken to pieces, equally attenuated on all ſides, and at laſt made round into Balls, of which he thinks fit to make Light, and which he diffuſes abundantly throughout the Univerſe. B 4 The

False.   The more wittily this Syſtem was imagin-
ed, the more the Reader will perceive it un-
worthy of a Philoſopher.   For, as nothing of
all this is proved, it were full as reaſonable to
admit the cold and hot, the dry and hu-
mid.   What does it ſignify which of the two
Errors be preferred !   We will not loſe time
in diſputing this creation of Cubes and three
Elements, or rather this Chaos.   Let us con-
tent ourſelves with obſerving here the Philo-
ſophical Errors into which the Syſtematical
Spirit, or Fondneſs for Syſtem carried the ſub-
lime Genius of *Deſcartes*; and let us refute
eſpecially only thoſe Errors, which having
the air of Truth, have gained Credit, and de-
ſerved to be advanced.

According to *Deſcartes*, the Light does not
proceed to our Eyes from the Sun, but is a
globulous Matter diffuſed univerſally, which
the Sun impels, and which preſſes upon our
Eyes as a Staff puſhed at one end preſſes the
ſame inſtant at the other.   This appeared
plauſible, but is not therefore the leſs falſe :
Deſcartes however was ſo fully convinced of
this Syſtem, that in his ſeventeenth Letter of
the third Volume, he poſitively ſays and re-
peats

peats it: *I confess that I know nothing of Philosophy, if the Light of the Sun is not transmitted to our Eyes in an instant.* And indeed, we must own, that as great a Genius as he was, he knew very little of true Philosophy; and wanted the Experiments of the succeeding Age. That Age is as much superior to *Descartes,* as *Descartes* was to Antiquity.

1. If Light were always diffused, and always existing in the Air, we should see as clearly in the Night as we do in the Day, because the Sun below the Hemisphere would continually impel the Globules on all sides, and the Impression equally affect our Eyes. *Of the progressive Motion of Light.*

2. It is demonstrated, that Light flows from the Sun, and we know, that it is very near seven or eight Minutes in coming to us from so immense a distance, which a Cannon-bullet retaining its force could not do in five and twenty Years.

The Author of the *Spectacle de la Nature,* a Work of great Merit, has fallen in this point into a small Mistake, which no doubt he will correct in the next Edition of his Work. He says, that Light, according to *Newton,* is seven Minutes in coming to us from the Stars; *Error in Spectacle de la Nature.*

he

he has taken the Stars for the Sun. Light
is fix Months in coming to us from the near-
eft of them, according to a certain Calcula-
tion, founded upon Experiments very delicate,
and at the fame time very imperfect. It is
not *Newton*, but *Huygens* and *Hartfoeker*,
who have advanced this Suppofition : he fays
alfo, to prove that God created Light before
the Sun, *That Light is diffufed throughout all
Nature, and makes itfelf fenfible, when the lu-
minous Stars impel it* ; but it has been demon-
ftrated to be very long in coming from the
fixed Stars to us.   Now, if it comes fo far,
it was not diffufed before.   It is neceffary to
be aware of thefe Errors, which are every day
repeated in abundance of Books, that are a
kind of Ecchoes to each other.

The following is in a few words the Sub-
ftance of *Romer*'s fenfible Demonftration, that
Light employs feven or eight Minutes in its
Paffage from the Sun to the Earth.

Demon-
ftration of
the Motion
of Light.
From the Earth at C, a Satellite of *Jupiter* is
obferved to be eclipfed regularly once in two and
forty Hours and an half. If the Earth were im-
moveable, the Obferver at C would fee thir-
ty Emerfions of that Satellite in thirty times

two

Satellites

B

A   Jupiter

C   G

Orbit of the Earth

D   H
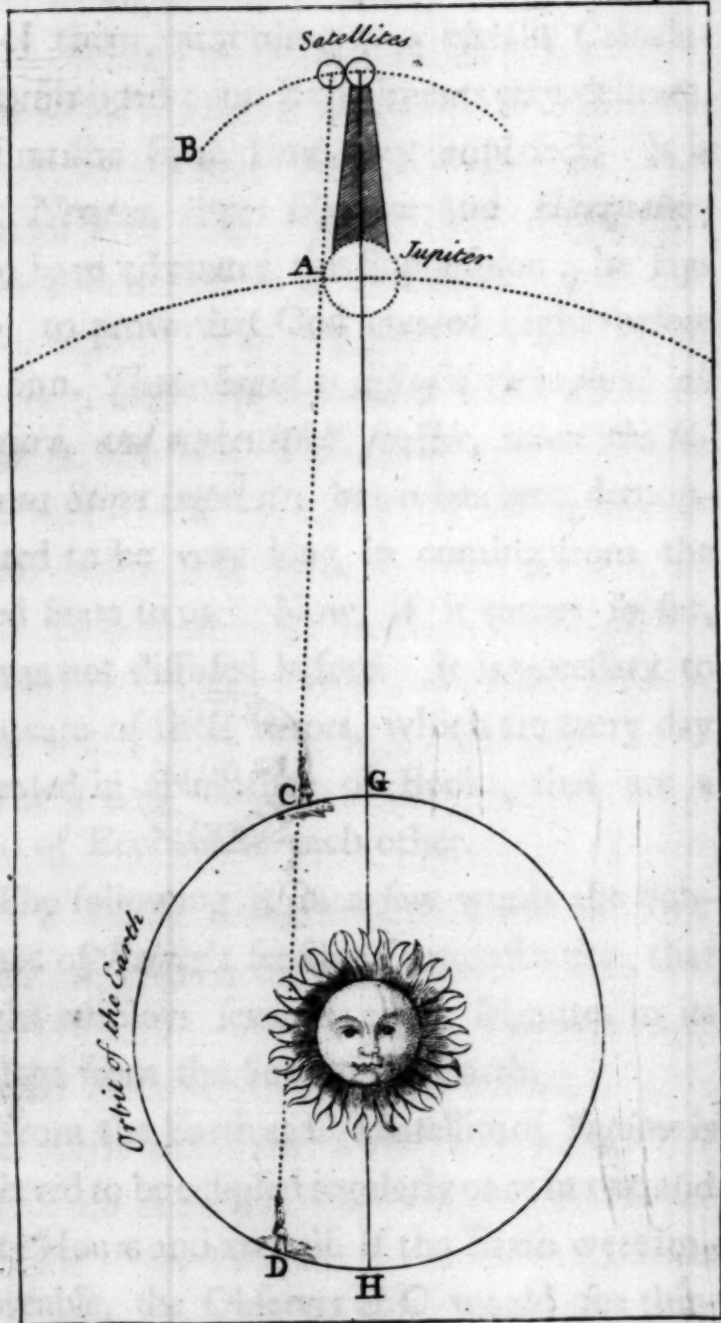
two and forty Minutes and an half; but at the end of that time the Earth is come to D, and then the Obferver fees no longer that E-merfion exactly at the end of thirty times two and forty Hours and an half; but muft add the time, which Light takes in paffing from C to D, which time is manifeftly con-fiderable. But this fpace C D is lefs than the fpace G H, for C D is a Chord of the Circle, and G H its Diameter. This Circle is the great Orbit defcribed by the Earth around the Sun in the Center; Light in coming from the Satellite of *Jupiter* paffes the Chord C D in ten Minutes, and G H in fifteen or fixteen. The Sun is between G and H; the Light therefore is feven or eight Minutes in coming from the Sun.

Mr. *Bradley,* in the laft place, has obferved by reiterated and certain Experiments, that many Stars viewed at different times, appear-ed fometimes a little more towards the South, and fometimes a little more towards the North; which difference, he has proved, could arife only from the annual Motion of the Earth, and the Progreffion of Light. He obferves, that if thefe Stars have a Parallax, it can be only of one Second. Admit-

Admitting this, I proceed to reafon in the following manner : a Star, whofe annual Parallax is no more than of one Second, is four hundred thoufand times more remote from us than the Sun ; if Light be eight Minutes in coming from the Sun to us, as Mr. *Bradley* believes, it will in confequence be fix Years, and above a Month, in coming to us from thofe Stars. But this is not all. Thefe are Stars of the firft Magnitude, thofe therefore of the fixth, being fix times more diftant, cannot tranfmit their Light to us in lefs than thirty fix Years and an half.

3. The Rays, diverted and forced to take a new Courfe by a Prifm, demonftrate, that Light actually moves, and is not a Quantity of Globules or Balls fimply preft.

4. If Light confifted of Globules exifting every where in the Air, a fmall hole cut in a dark Chamber ought to illuminate it entirely : for Light impelled in every manner thro' the little Hole would act on all fides, as Balls of Ivory difpofed in a circular or fquare Form would difperfe themfelves on all fides, if only one of them were ftrongly moved ; but directly the contrary happens. For the Light

received

received at a small Hole, which admits but few Rays to pass thro' it, scarce illuminates half a Foot of the place upon which it falls.

5. The Light always enters a Hole in a right Line, in whatever manner the Hole can be contrived; but if the Balls were simply pressed, it would be impossible for that Pressure to be in a right Line. It is evident therefore, that *Descartes* is mistaken as well in regard to the Nature of Light, as the manner in which it is transmitted to us.

Father *Mallebranche*, whose Genius was more subtile than true, and who always consulted his Meditations, but not always Nature, adopted the Elements of *Descartes* without Proof; but he made some Alterations in that inchanted Castle. He imagined without other Proof another Explanation of Light. *F. Mallebranche's Error.*

The Vibrations of luminous Bodies impress, according to him, Strokes or Motions upon small and gentle Whirlings, capable of Compression, and entirely composed of subtile Matter. But had *Mallebranche* been asked, in what manner these small and gentle Whirlings transmitted Light to our Eyes; how the Sun's Action could pass in an instant thro'

thro' fo many fmall Bodies comprefled upon
one another, of which a very fmall number
were fufficient to intercept that Action; and
laftly how it happened, that thofe gentle
Whirlings did not mingle in turning upon one
another: What would that Father have re-
plied? Upon what Foundation did he build
this imaginary Superftructure? Should Men
who talked of nothing but *Truth*, have wrote
nothing but Romances!

Definition of Light.   What then at length is Light? It is *Fire*
itfelf, which burns at a fmall diftance when
its Parts are lefs attenuated, or more rapid, or
more united; and which gently illuminates
our Eyes, when it acts from a greater di-
ftance, and its Particles are more rare, and
lefs rapid, and lefs united.

Thus a lighted Candle would burn the Eye
at the diftance of only fome Lines (twelfths)
of an Inch, and gives it Light at that of fome
Inches.   Thus the Rays of the Sun, diffuf-
ed thro' the Spaces of the Air, illuminate Ob-
jects, and collected by a Burning-Glafs melt
Lead, Gold, &c.

This Fire is darted on all fides from the
Point irradiating: which is the caufe of its

being

being seen on all sides ; it is therefore always to
be considered, as Lines issuing from a Center
to a Circumference. Thus every Irradiation,
or Groupe of Rays, from the Sun or any Fire
whatsoever, should be considered as a Cone,
of which the Base is upon our Eye, and the
Vertex at the Fire that darts it.

This Matter of Fire is thrown from the Sun
to us, and as far as *Saturn*, &c. with a Ra-
pidity that amazes the Imagination.

The Calculation of it shews, that if the
Sun is four and twenty thousand Semi-diame-
ters of the Earth from us, Light in its Pro-
gression to us from that Star, is but a Second
in coming about a thousand million of Feet.
Now a Bullet of a Pound Weight, discharg-
ed with half a Pound of Powder, flies but
six hundred Feet in a Second ; so that a Ray
of the Sun (to make the Numbers even) is
one million, six hundred and six thousand,
six hundred times more rapid than a Cannon-
ball.

I shall not enter here into the famous Dis-
pute *De vivis viribus* ; I refer the Reader for *See Me-moirs of the Academy,* that to the learned and profound Dissertation *&c.* 1728. of Mr. *Mairan.*

I

I hope that Philofopher, and thofe who moft oppofe the Doctrine of living Powers, will permit me with the utmoft Rigour to advance the following Propofition.

The Effect produced by the Force of a Body in motion, at leaft when uniform in its Rapidity, is the Product of its Quantity by the Square of its Acceleration; that is to fay, that a Body, if it has ten Degrees of Swiftnefs, will *(cæteris paribus)* make an hundred times as much Impreffion as it would do, if it had only one Degree of Swiftnefs.

If therefore a fingle Particle of Light acts in proportion to the Square of its Swiftnefs, and if that Force is about fixteen hundred thoufand to that of a Bullet, that Square will be 2560000000000, it follows then, if that Atom is only two billions, five hundred and fixty thoufand millions of times lefs than a Pound, it will however have the fame Effect as a Cannon-ball. Suppofe this Atom ftill a thoufand millions of times lefs; one Moment's Emanation of Light would deftroy all the Vegetables upon the Face of the Earth. Imagine how fmall a Particle of Light is, which paffes fo eafily through Glafs; and to have

Extreme minutenefs of the Particles of Light.

have some Idea of Infinite, conceive what that Matter still a million of Degrees more subtile must be, that enters the Pores of Gold and the Loadstone, and penetrates the Rocks and the Bowels of the Earth.

The Sun which darts this luminous Matter to us in seven or eight Minutes, and the Stars, those other Suns, which transmit it to us in several Years, supply us eternally without wasting almost in the same manner, as the Creature that produces Musk, perpetually emits odoriferous Bodies around it, without any sensible diminution of its Weight.

In fine the Rapidity, with which the Sun projects its Rays, is in proportion to its Magnitude, which is about a million to one, to that of the Earth, and to the Swiftness of the Motion, with which that immense Body of Fire turns round upon its own Axis in twenty five Days and an half.

The Force, Illumination, Intenseness and Density of all Light is calculated. This Calculation shews, that this Force is exactly in proportion to the Force, with which Bodies fall, and with which *Newton* proves all the heavenly Bodies attract one another. This

C Propor-

Proportion is called the inverfe Rule of the Square of the Diftances. It will be neceffary to familiarize ourfelves with this Expreffion.

Proportion in which all Light acts.
Its Signification is fimple and intelligible : it is, that a Body at the diftance of four Feet from any Fire, will be fixteen Times lefs heated and illuminated, than a Body at the diftance of one Foot, fixteen is the Square of Four. Now Four is the diftance of the Body lefs illuminated; the Light therefore tranfmits to this Body diftant four Feet, not four but fixteen Times lefs Rays. And this is called the Ratio, or Rule, inverfe of the Square of the Diftances, which ought to be well underftood ; for this Proportion will be one of the Principles, on which the New Philofophy is founded, which we fhall endeavour to make eafy.

Progreffion of Light. Proof of the Impoffibility of a Plenum.
We may here take occafion to conclude from the Rapidity, with which the Subftance of the Sun tranfmits itfelf to us in this manner in a right Line, how chimerical the Plenum of *Defcartes* is. For firft, how could it come to us in a right Line, thro' fuch immenfe Spaces of Matter moved in a curve Line, and thro' fuch an Infinity of different Motions? 2. How could fo rare a Body in

<div align="right">feven</div>

seven or eight Minutes pass thro' the Space of thirty millions of Leagues between us and the Sun, if it was to penetrate a resisting Matter all the way. In that Case every Ray must displace thirty millions of Leagues of subtile Matter in a Moment. Besides which, we are to remember, that this pretended subtile Matter would resist in the absolute Plenum, as much as the most solid Matter. For a Pound of Gold-dust, pressed close in a Box, resists as much as a piece of Gold weighing a Pound. So that it would be necessary for a Ray of the Sun to have much greater Force, than if it were to penetrate thro' a Cone of Gold, of which the Axis should be thirty millions of Leagues.

Experience, that true Guide of Philosophy, further shews us, that Light in coming from one Element into another, from one Medium into another, does pass through entire, as we shall observe : a great Part of it is reflected; the Air repelling more of it than it transmits ; so that it would be impossible for the Light of any of the Stars to reach us ; it would be wholly repelled and absorbed, before a single Ray could come half way to

C 2   our

our Atmoſphere. But in the Chapters, where
we ſhall explain the Principles of Gravita-
tion, we ſhall prove by a multitude of Argu-
ments, that this pretended Plenum was a
Romance.

Let us here ſtop a Moment to obſerve how
ſlowly Truth eſtabliſhes itſelf amongſt Man-
kind.

It is almoſt fifty Years ſince *Romer* de-
monſtrated by Obſervations upon the Satel-
lites of *Jupiter*, that Light is tranſmitted
from the Sun to the Earth in about ſeven
Minutes and an half, notwithſtanding which
the contrary is not only maintained in many
Books of Phyſicks ; but in a Collection upon
that Subject in three Volumes extracted from
the Obſervations of all the Academies in *Eu-*
rope, printed 1730, pag. 35, Vol. I. there is
this Paſſage.

" Some have pretended, that a luminous
" Body as the Sun, emits continually an
" Infinity of ſmall inſenſible Particles, which
" bring the Light to our Eyes ; but this
" Opinion, which ſtill favours a little of
" the old Philoſophy, cannot be maintain-
" ed."

This

This Opinion is however demonstrated in more than one manner, and is so far from favouring of the Old Philosophy, that it is directly contrary to it; for can any thing be more contrary to Words void of Sense, than Measures, Calculations and Experiments?

C 3   CHAP.

CHAP. II.

The Property, which Light has of re-
flecting itself, was not truly known.
It is not reflected by the solid Parts
of Bodies as vulgarly believed.

HAVING seen what Light is, from
whence derived, and how long it is in
coming to us, let us proceed to its Properties
and Effects, unknown till our Days. The
first of its Effects, is its seeming to rebound
from all Objects to bring the Images of them
to our Eyes.

All Men, all Philosophers, *Descartes, Malle-*
branche, and such as are most remote from
vulgar Opinion, have equally believed, that
the solid Surfaces of Bodies are what actually
reflect Light to us. The more smooth and
solid a Surface is, the more, they say, it
causes the Light to rebound from it; the lar-
ger, and the more direct the Pores of the
Body are, the more the Rays of Light pass
thro' its Substance. Thus the Looking-glass,
covered at bottom with a Surface of Quick-
silver, reflects all the Rays; and the same
Glass

Glafs without Quickfilver, having direct and large Pores in great number, lets great part of the Rays pafs thro' it. The more large and direct Pores a Body has, the more tranfparent it is: fuch is, faid they, the Diamond, fuch the Water itfelf; and thefe were the Ideas generally received, which no-body called in queftion.

Yet all thefe Ideas are entirely falfe, fo remote often is the Likenefs of Truth from the Truth itfelf. The Philofophers gave into this Error, in the fame manner the Vulgar entirely miftake, when they imagine the Sun no larger than it appears to the Eye. In this confifted the Error of the Philofophers:

There is no Body, whofe Surface we can really make even. However the Surfaces of many feem perfectly fmooth and polifhed: and whence do they appear fo to us? The moft fmooth Superficies, in refpect to the Particles, of which Light is compofed, is no more than a great number of Mountains, Cavities, and Spaces, fo that the Microfcope difcovers, that the Point of the fineft Needle actually abounds with Eminences and rugged Parts.

All

All the various Rays of Light, which should fall on these unequal Parts, would be reflected according as they should fall, and falling unequally, would never be regularly reflected, for which reason we could never see ourselves in a Glass.

The Light therefore, which presents us our Image in a Looking-glass, undoubtedly does not proceed from the solid Parts of the Superficies of that Glass ; neither is it the Effect of the solid Parts of the Mercury Pewter spread upon its Back. Those Parts are not more even or more smooth than the Glass itself. The solid Parts of the Pewter and Mercury are incomparably larger than the constituent solid Parts of Light, therefore if the small Particles of Light fall upon the gross Parts of the Mercury, they will spread and scatter themselves on all sides, like Grains of Lead falling upon Rubbish. What unknown Power then is it, that causes Light to rebound towards us with so much Regularity ? It appears already, that Bodies do not return it in this manner. What seemed the most known and incontestible amongst Mankind, becomes a greater Mystery than

than the Weight of the Air was formerly. Let us examine this Problem of Nature, and our Wonder will encrease. We cannot inform ourselves in it without Surprize.

Take a small piece, a Cube of Cryftal, and you will find the Rays of the Sun fall on this folid tranfparent Body in this manner.
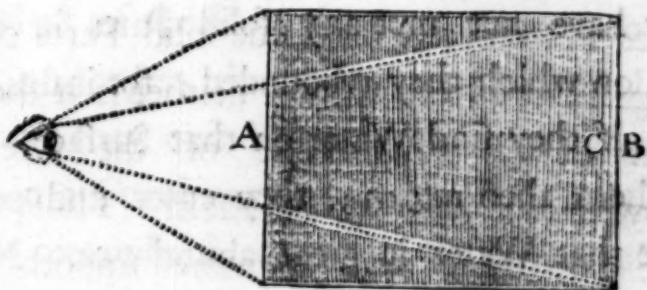
1. A fmall part of the Rays rebound to the Eye from the neareft Surface A, even without touching that Surface, as will be proved more at large.

2. Part of the Rays are received into the Subftance of this Body, where they play, lofe themfelves, and extinguifh.

3. A third Part reach to the Infide C of the Surface B, and from near the Surface B return into A, from whence fome come to the Eye.

4. A fourth Part paffes into the Air.

5. A

5. A fifth Part, which is the moſt conſiderable, returns from beyond the fartheſt Surface B into the Cryſtal, which it repaſſes, and comes to reflect itſelf to the Eye. Let us here examine theſe latter Rays, which having paſſed the fartheſt Surface B, and come to the Air, fly back from that Air towards us, re-entring thro' the Cryſtal. They undoubtedly have not met any ſolid Parts in that Air, on which they rebounded; for inſtead of Air, if they find Water on that Surface, few of them then return; they enter and penetrate that Water in great abundance. Now Water is about eight hundred Times heavier, more ſolid, and leſs rare than Air. Theſe Rays however do not rebound from this Water, but they rebound from that Air into the Glaſs; therefore the Light is not reflected by the ſolid Parts of Bodies.

The following is a more ſingular and more deciſive Obſervation. Expoſe in a dark Chamber this Cryſtal A B, to the Rays of the Sun in ſuch a manner, that the Light coming on the Superficies B, makes an Angle of above forty Degrees with the Perpendicular.
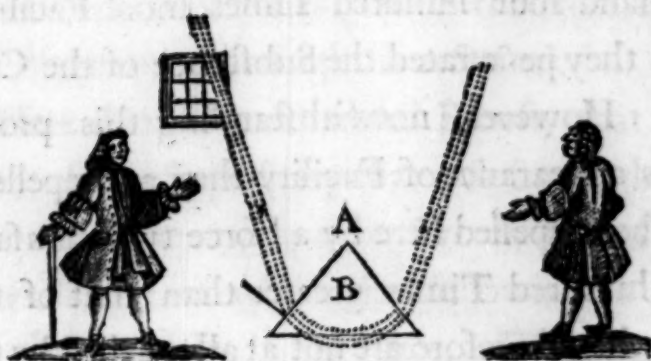
Most of the Rays then penetrate into the Air no longer, they re-enter the Cryſtal the inſtant they quit it, they return, as you ſee, but in a Curve not Perceptible.

It certainly is not the ſolid Surface of the Air that repels them into the Glaſs; many of thoſe Rays entered the Air before, when they fell leſs obliquely; why therefore with an Obliquity of forty Degrees, nineteen Minutes, do moſt of thoſe Rays paſs no longer? Do they find more Reſiſtance, more Matter in the Air at this Degree, than in the Cryſtal they had penetrated? Are there more ſolid Parts in the Air at forty Degrees and one third, than at 40? The Air is almoſt two thouſand four hundred Times more rare, leſs weighty, and leſs ſolid than the Cryſtal, thoſe Rays therefore ought to paſs into the Air with two

<div align="right">thouſand</div>

thoufand four hundred Times more Facility, than they penetrated the Subftance of the Cryftal. However, notwithftanding this prodigious appearance of Facility they are repelled; but then repelled here by a Force two thoufand four hundred Times greater than that of the Air; they therefore are not at all repelled by the Air; again, the Rays are not reflected to our Eyes by the folid Parts of Matter. For Light rebounds fo little from the folid Parts of Bodies, that in reality it rebounds from Vacuity.

We have juft feen, that Light falling in an Angle of 40 Degrees 19 Minutes upon the Cryftal, rebounds almoft entirely from the Air, which it finds at the fartheft Surface of the Cryftal. Let Light fall on it, in an Angle lefs only one Minute, ftill lefs of it will pafs beyond that Surface into the Air. Remove the Air, and no Rays at all will pafs. This is a thing demonftrated.

Now when there is Water upon this Surface, many Rays enter that Water, inftead of being reflected by it. When there is only Air fewer Rays enter that Air. When there is

no

no Air, no Ray paffes; it is therefore from the Vacuum that Light is reflected.

Here then are undoubted Proofs, that it is not a folid Superficies that reflects Light to us: there are many other Proofs ftill of this new Truth; of which the following is one, we fhall explain in its Place. Every opaque Body reduced to a thin Plate, fuffers Rays of a certain kind to pafs through its Subftance, and reflects other Rays: now, if Light were reflected by Bodies, all the Rays which fhould fall upon thefe Plates, would be reflected by them. To conclude, we fhall fee that fo a-ftonifhing a Paradox never had a greater variety of Proofs. Let us begin then by familiarizing ourfelves with thefe Truths.

1. This Light, which is imagined to be reflected by the folid Surface of Bodies, returns in Effect without having touched that Surface.

2. Light is not reflected from the Back of a Looking-glafs by the folid Surface of the Quickfilver, but from the very Pores of the Looking-glafs and the Quickfilver.

3. It is not neceffary, as it has hitherto been thought, that the Pores of that Quickfilver
<div align="right">fhould</div>

should be very small to reflect Light; on the contrary, it is neceſſary that they ſhould be large.

To thoſe who have not ſtudied this Philo-ſophy, it will be new matter of Surprize to hear it ſaid, that the Secret of rendering a Body opaque, is often to enlarge its Pores, and that the Means to make it tranſparent, is to make them ſmall. The Order of Na-ture appears entirely changed : what ſeemed the neceſſary Cauſe of Opacity, is directly the Cauſe of Tranſparence ; and what appeared to render Bodies tranſparent, is become what makes them opaque. Nothing however is more true, as the groſſeſt Experiment demon-ſtrates.

A piece of dry Paper, of which the Pores are very large, is opaque, no Ray of Light paſſing thro' it : reduce thoſe Pores, by ma-king it imbibe Water or Oil, it becomes tanſparent ; as will alſo Linen, Salt, &c.

There are then certain unknown Principles, which produce theſe Wonders, certain Cauſes, which occaſion Light to rebound, before it touches a Surface, which reflect it from the Pores of tranſparent Bodies, and which re-

pel it from the very midft of Vacuity; we are inevitably obliged to admit thefe Facts, whatever the Caufe of them may be.

Let us then apply ourfelves to the other Myfteries of Light, and let us fee whether thefe furprizing Effects may be traced to fome inconteftbile Principle, which we muft neceffarily admit as well as the Effects themfelves.

CHAP.

CHAP. III.

Of the Property which Light has of refracting in passing from one Substance into another, and of taking a new Course in its Progression.

THE second Property of the Rays of Light, which it is necessary to examine well, is that of taking a new Direction in its Passage from the Sun into the Air, from the Air into Glass, from Glass into the Water, &c. It is this new Direction in these different Mediums, or breaking of the Light, which is called Refraction, by which Property an Oar in the Water appears crooked to the Rower; it is that occasions our seeing the Object in a Bowl, by putting Water in it, which we could not see before at the same Place.

In short it is by the means of this Refraction that our Eyes enjoy Sight. The admirable Secrets of Refraction were unknown to the Ancients. Notwithstanding its being before their Eyes, and their perpetual Use of it, they have not left us a single Tract,

to induce us to believe that they had gueſſed
the reaſon of it. Thus to this Day we ſtill
continue ignorant even of the Cauſe of the
Motions of our Bodies, and of the Thoughts
of our Souls; but this Ignorance is of a diffe-
rent kind. We neither have nor ever ſhall
have Inſtruments of ſo exquiſite a Frame, as
to enable us to inſpect the firſt Springs, the vi-
tal Principles of ourſelves; but human Induſ-
try has formed itſelf new Eyes, which has
ſupplied us with the means of prying into
the Effects of Light, almoſt as far as it is
permitted for Man to know concerning them.

Let us here form a clear Idea of a very *In what*
common Experiment. Suppoſe a piece of *manner Light is*
Gold in this Baſon, and your Eye fixed on *refracted.*
the ſide of the Baſon, at ſuch a diſtance, that
you cannot ſee the Piece:

D Let

Let Water be poured into it, you did not
see the Money at first where it was: but now
you see it where it is not; how happens
this?

The Object A reflects a Ray, which strikes
the side of the Bason, and which will never
reach your Eye: it also reflects the Ray A B,
which passes above your Eye; but when you
receive this Ray A C, it is not your Eye that
has changed its Place, but it is the Ray A C;
that has manifestly taken a new Direction
at the Edge of the Bason in passing from the
Water into the Air, and thereby strikes your
your Eye from C.
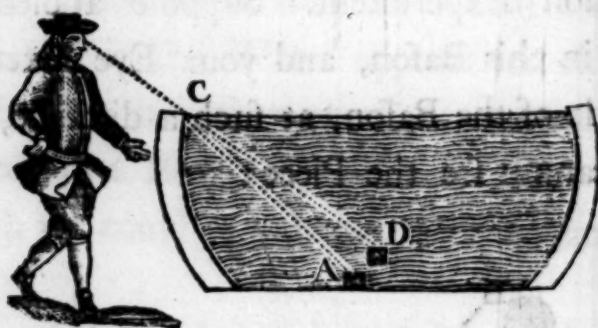
For you always see Objects in a right
Line, therefore you see the Object in the
right Line C D, and at the Point D, above
the Place where it really is.

If this Ray is broke in one manner, when it paſſes from the Water into the Air, it muſt break in a contrary manner, when it enters the Water from the Air.
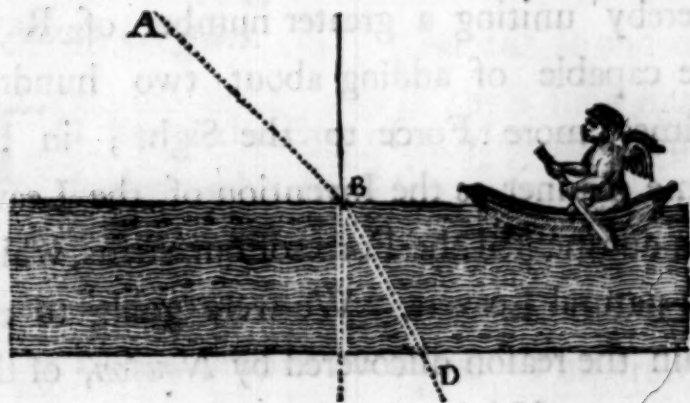
I raiſe a Perpendicular from this Water; the Ray, from the luminous Point A is broke at the Point B, and approaches the Perpendicular in the Water by the Line B D. The ſame Ray D B in its Progreſſion from the Water into the Air, is broke in paſſing towards A, and removing from the ſame Perpendicular; Light therefore is refracted differently, according to the Mediums through which it paſſes. It is upon this Principle that Nature has diſpoſed the different Humours in our Eyes, in order that the Rays of Light, in their Paſſage thro' thoſe Humours, may be

broke

broke in such a manner, as to reunite after
in a Point upon the Retina: to conclude, it
is upon the same Principle, Spectacles are
made, which occasion still greater Refrac-
tions than those of the Eye, and which,
thereby uniting a greater number of Rays,
are capable of adding about two hundred
Times more Force to the Sight; in the
same manner as the Invention of the Leaver
has augmented the Force of our Arms, which
are natural Leavers. We were going to ex-
plain the reason discovered by *Newton*, of this
Property of Light; but it is necessary to know
first in what manner this Refraction acts in our
Eyes, and how the Sense of Sight, the most
extensive of all the Senses, owes its Existence
to Refraction. How well soever we conceive
this Matter, it will not be amiss to strengthen
the Reader's Ideas of it by a new Enquiry.
Those who peruse this little Work, will not
be displeased with having no occasion to seek
elsewhere for what they may desire to know
concerning the Sight.

C H A P.

CHAP. IV.

Of the Form of the Eye, and in what manner Light enters and acts in that Organ.

TO know the Eye of a Man as a Philo-
fopher who confiders only Vifion, it
is neceffary to know firft, that the firft white
Cover or Coat, the Defence and Ornament
of the Eye, tranfmits no Rays. The ftronger
and fmoother this White of the Eye is, the
more Light it reflects; and when fome warm
Paffion brings unufual Spirits to the Vifage,
they ftrain and actuate this Membrane in
fuch a manner that the Eyes feem to flafh
like Fire.

In the midft of this Membrane, the Cor-
nea of the Eye raifes itfelf a little, being thin,
hard and tranfparent, exactly like the Glafs
of a Watch, when placed upon a Bowl in
this manner.

D 3
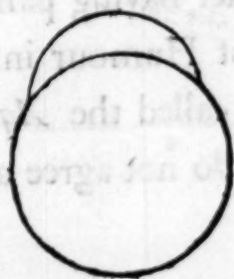
Under this *Cornea*, is the *Iris* another
Membrane, which being coloured of itself,
diffuses its Colour upon this transparent *Cor-
nea* that covers it. It is from this *Iris*, some-
times blue and sometimes brown, that the
Eyes are either blue or black. It is perforat-
ed in the middle, which therefore always ap-
pears black, and is called the Sight of the
Eye. Through this opening the Rays of
Light enter; it enlarges itself by an involun-
tary Motion in dark Places for the reception
of more Rays, and contracts again, when
too much Light offends it.

The Rays admitted through this Sight
are before considerably refracted in passing
through the *Cornea* with which it is covered.
Imagine this *Cornea* like the Glass of a Watch,
that is Convex without, and Concave within:
all oblique Rays are broke in passing this
Glass; but afterwards its Concavity re-instates
what its Convexity has broke. This is what
happens in the *Cornea*. The Rays so broke
and dispersed, after having passed the *Cornea*,
find a transparent Humour into which they
enter. This is called the *Aqueous Humour*.
The Anatomists do not agree amongst them-
selves

Cor nea

Iris Humour

Aqueous

Aqueous Humour

Cris talline

Vitreous Humour

Retina where the Rays paint Objects
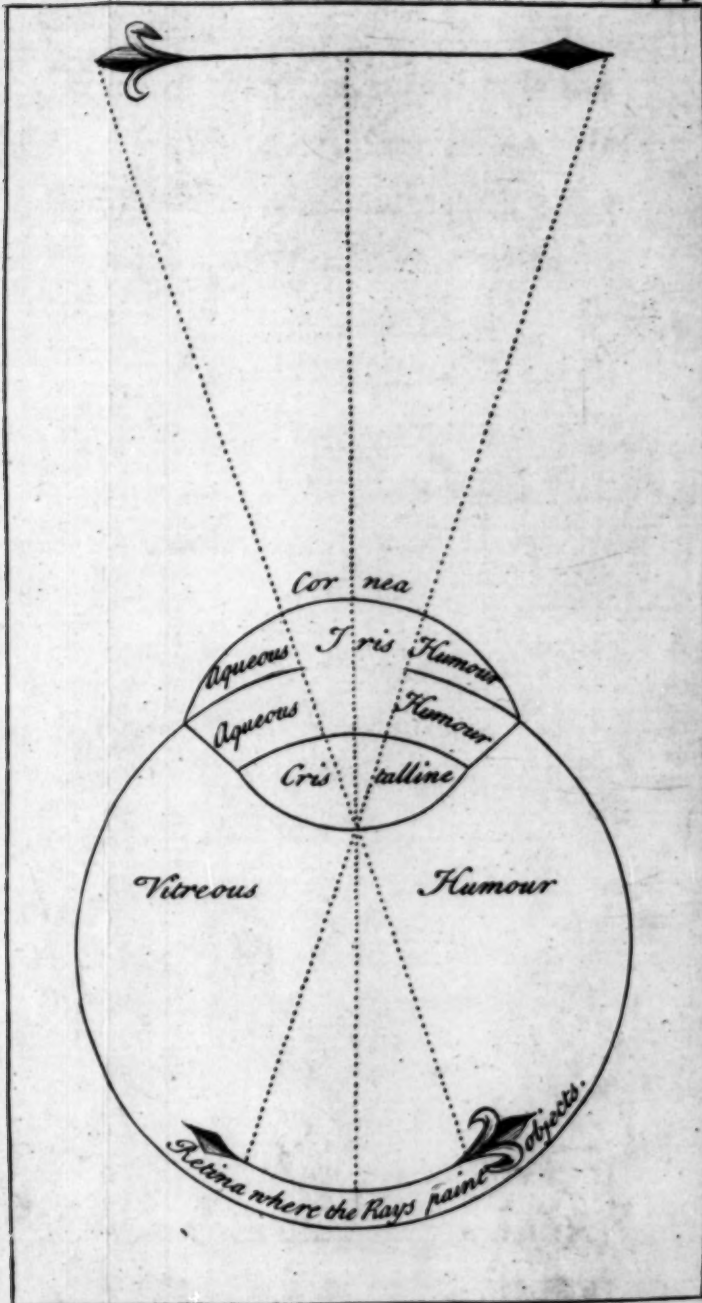
felves concerning the Form of this little Re-
fervoir. But, whatever its Figure be, Na-
ture feems to have placed this clear and lim-
pid Humour there, to caufe Refractions, to
tranfmit the Light clearly, and that the Cryftal-
line Humour which is behind it may advance
without difficulty, and change Figure freely, and
that the neceffary Humidity be preferved, *&c.*

The Rays having paffed this Water, come
to a kind of liquid Diamond, in the Form
of a Lentil, and fet in a fine Membrane, which
is itfelf tranfparent. This Diamond is the
Cryftalline Humour, that breaks all oblique
Rays, and is the principal Organ of Refrac-
tion and Sight; in that refpect perfectly
like a Spectacle-glafs of the fame Form. Sup-
pofe this Figure the Cryftalline Humour or
Lenticular Glafs.

The
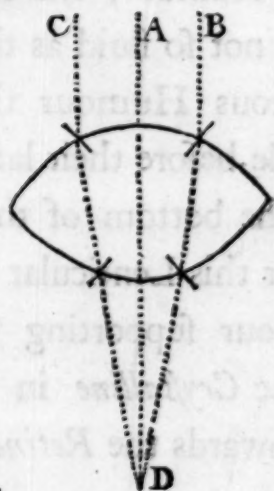
The perpendicular Ray A penetrates it, without being broke; but the oblique Rays B, C, break in paſſing this Glaſs, approaching the perpendicular Rays which are drawn here on the Places where they fall. Afterwards, when they quit the Glaſs to paſs into the Air, they break again removing as you ſee from the Perpendicular; this new Refraction is exactly what makes them converge in D, the Focus of the Lenticular Glaſs.

Now the *Retina*, that ſlight Membrane, that Expanſion of the Optick Nerve, which covers the bottom of the Eye, is the Focus of the Cryſtalline Humour: it is to this *Retina* that the Rays tend; but before they reach it, they again meet a new Medium through which they paſs; this new Medium is the Vitreous Humour, leſs ſolid than the *Cryſtalline*, but not ſo fluid as the *Aqueous*.

In this Vitreous Humour the Rays have time to aſſemble before their laſt Union upon the Points of the bottom of the Eye. Imagine then under this Lenticular *Cryſtalline*, the Vitreous Humour ſupporting it; that Humour holds the *Cryſtalline* in its Concavity, and is round towards the *Retina*.

The

D   D

Decayed   Eye

A   A   A

Eye, in which the Cristalline is flat
thro' age or disease.

The Rays in paffing this laft Humour finally Converge. Every Groupe of Rays, that iffues from a Point of an Object, ftrikes upon a Point of the *Retina.*

A Figure in which each Part of an Eye is marked with its proper Name, will better explain all this Mechanifm, than Lines and A's or B's can do. The Structure of the Eyes being thus underftood, the reafon why the aid of Glaffes is fo often neceffary, and the Ufe of Spectacles, may eafily be known.

An Eye will often be too flat either thro' *Decayed* the Formation of the *Cornea,* or its Cryftal- *Eye.* line Humour, which Age or Difeafe may have dried up; the Refractions will then be too weak and in lefs Quantity, nor will the Rays be collected any longer upon the *Retina.* Let us confider this too flat Eye, and call it for Diftinction fake the *Decayed Eye.*

For the greater Facility, let us obferve only three Groupes or Cones of Rays falling from the Object on this Eye. They will reunite at the Points A, A, A, beyond the *Retina,* and in Confequence the Objects will be feen confufed.

Nature

Nature has fupplied an Help againſt this
Inconvenience, by the Power ſhe has given
the Muſcles of the Eye either to lengthen or
make it flat, to make it approach or withdraw
from the *Retina*. Thus in this decayed Eye,
the *Cryſtalline Humour* has the Faculty of ad-
vancing itſelf a little to D D: the Space then
between it and the bottom of the *Retina* be-
comes greater, and the Rays are brought to
unite upon the *Retina*, inſtead of going be-
yond it; but when that Power is loſt, hu-
man Induſtry ſupplies it, and a Lenticular
Glaſs is placed between the Object and the
decayed Eye. The Effect of this Glaſs is
to draw the Rays it receives cloſe together,
which it conveys to the Eye both more col-
lected and in greater Number: theſe reach
the *Retina* in the Points they ought, and the
Sight is then clear and diſtinct.

*Short-
ſighted Eye.* Obſerve this other Eye, which has a con-
trary Defect, it is too round. The Rays
unite too ſoon, as you ſee at the Point B,
they croſs each other too faſt, they ſeparate
in B, and from thence go on to make a Spot
upon the *Retina*. This is called *Shortneſs of
Sight*. This Inconvenience decreaſes in pro-
portion

Short
Sighted
Eye.

B   B
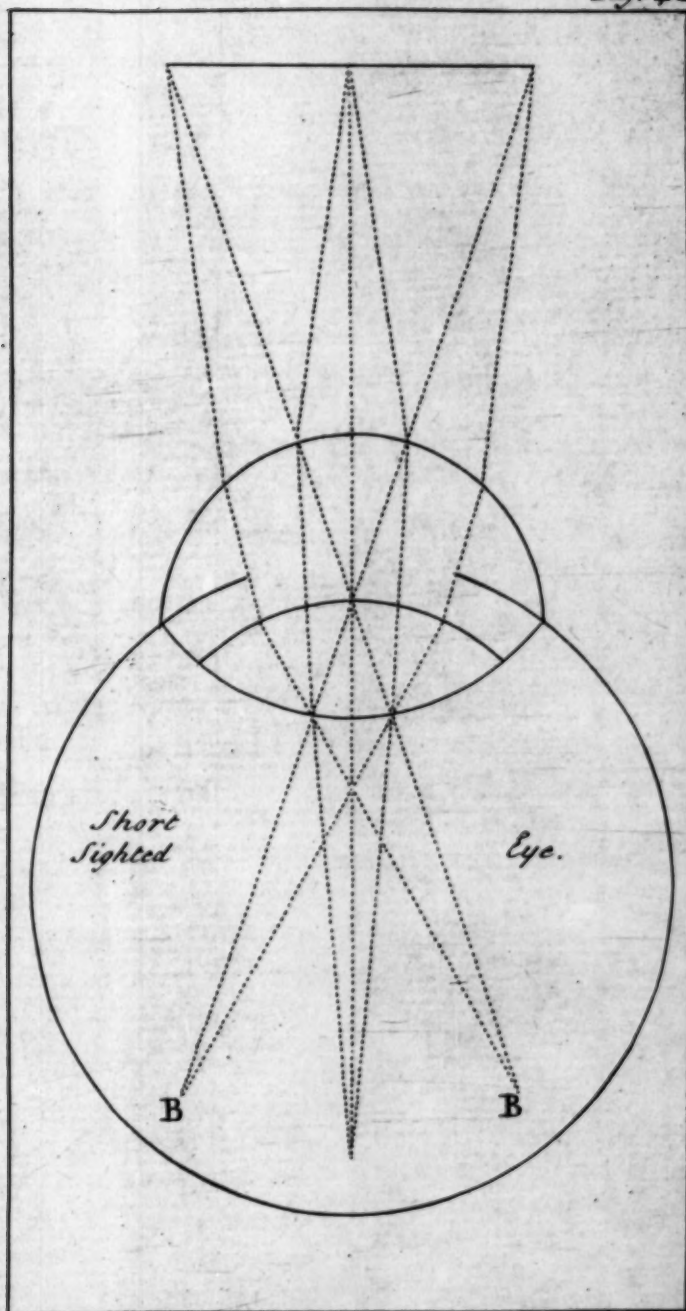
Eye, in which the Cristalline is too round,
and occasions Shortness of Sight.

portion as Age brings on others, such as Dryness and Weakness: these insensibly render this too round Eye flat, for which reason shortsighted Eyes are said to last the longest. At this time the Person, who was obliged to bring his Book to the Distance of two or three Inches from his Eye, can sometimes read at that of a Foot; but at the same time his Sight soon becomes troubled and confused, and he cannot see distant Objects; such is our Condition, one Defect can scarce ever be repaired but by another.

Now, whilst this Eye is too round, it is necessary to use a Glass, which prevents the Rays of Light from re-uniting too soon. This Glass will have a quite contrary Effect to the former, and instead of being Convex on both sides, must be a little Concave on both sides, to disperse the Rays, which the other collects. They will in Consequence unite farther in the Eye, than they did before, and the Eye will see perfectly well. The Convexity, and Concavity of Glasses are proportioned to the Defects of the Eyes; the same Glasses, that suit the Eyes of one old Man, will be of no Service to another, for there are neither

two

two Diseases, two Men, nor two Things exactly alike in the World.

The Ancients did not know these Spectacles. They knew however Burning-Glasses; the Discovery of one Truth in a Subject, is not always a reason for the Discovery of all the Truths it includes. The Attraction of the Load-stone was known, but its Direction to the Pole remained a Secret. The Demonstration of the Circulation of the Blood was evident, even in the Bleeding practised by all the Greek Physicians, notwithstanding which no-body suspected that the Blood circulated.

It is very likely that the Spectacles and Magnifying-Glasses, which give new Eyes to the Old, were discovered in the time of *Roger Bacon* in the 13th Century; for he is the first that speaks of them.

You have now seen the Effects caused by Refraction in our Eyes, whether the Rays reach them without any intermediate Aid, or pass thro' Crystals : you conceive, that without such Refraction in our Eyes, and such Reflection of Rays from above the Surfaces of Bodies, the Organs of Sight would be of no use to us. The Means employed by Nature in

caußng

caufing this Refraction, and the Laws fhe obferves, are Myfteries we are going to explain. But firft we muft conclude what we have to fay concerning Sight, and fatisfy thefe natural Queftions? Why do we fee Objects beyond, and not upon, the Looking-Glafs? Why does a Concave Looking-Glafs render Objects larger than they are? Why do Telefcopes draw Things nigh and magnify them? By what Artifice does Nature make us fenfible of Magnitudes, Diftances and Situations? And laftly, why do we fee Objects as they are, tho' reverfed on our *Retina?* All thefe Things merit the Curiofity of every Thinking Being? but we fhould not have enlarged upon Subjects, which fo many Illuftrious Writers have treated of, and fhould have referred to them, if we had not in view the making known fome Truths fufficiently new, and curious to a fmall number of Readers.

CHAP.

CHAP. V.

Of Looking-Glaſſes, and Teleſcopes: Reaſons given by Mathematicians for the Myſteries of Viſion; that thoſe Reaſons are not altogether ſufficient.

THE Rays, which a Power unknown till our Days, cauſes to reflect to the Eye from above the Surface of a Looking-Glaſs, without touching that Surface, and from the Pores of that Glaſs, without touching its ſolid Parts; theſe Rays, I ſay, return to the Eye in the ſame manner as they arrived at the Glaſs. If you ſee your Face in it, the Rays from your Face ſtriking parallel and almoſt perpendicular upon the Glaſs, return to it in the ſame manner as a Ball rebounds from the Floor.

Looking-Glaſs with a plane Surface. If in the Glaſs M, we look at an Object on one ſide of us as A, the Rays of that Object act in the ſame manner as a Ball, which ſhould rebound to B, the place of your Eye. This

4

This is called the Angle of Incidence equal to
the Angle of Reflection.
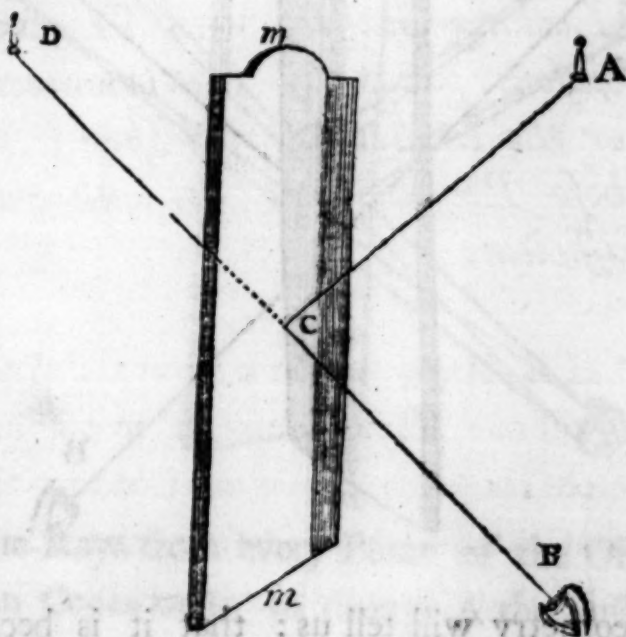
The Line A C is the Line of Incidence,
the Line C B is the Line of Reflection. It
is sufficiently plain, and the bare mentioning
demonstrates, that those Lines form equal
Angles upon the Surface of the Glass; where-
fore then do I not see the Object either in A
where it is, or in C from whence the Rays
come to the Eye, but in D behind the
Glass?
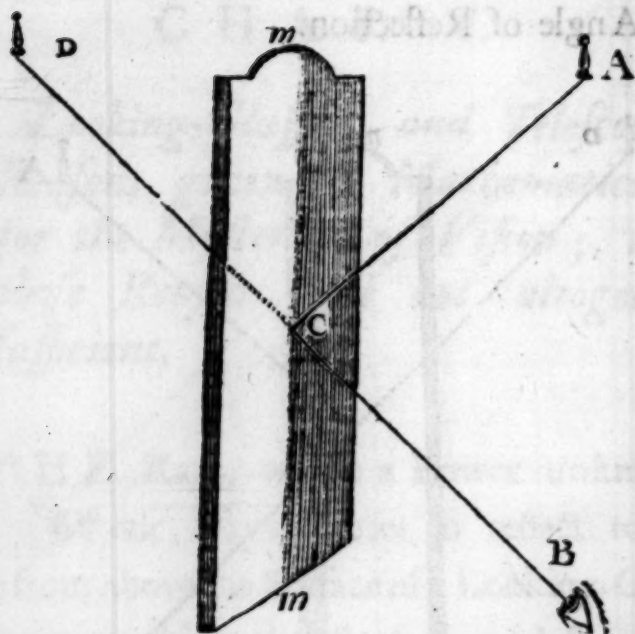
Geometry

Geometry will tell us : that it is becaufe the Angle of Incidence is equal to the Angle of Reflection : becaufe the Eye in B, carries the Object into D; becaufe Objects can act upon you only in right Lines, and becaufe the right Line continued from your Eye B, behind the Glafs to D, is as long as the Line A C, and the Line C B added together.

It will tell you alfo, that you never fee Objects but from the Point where the Rays begin to diverge. Suppofe the Mirror M I.

The
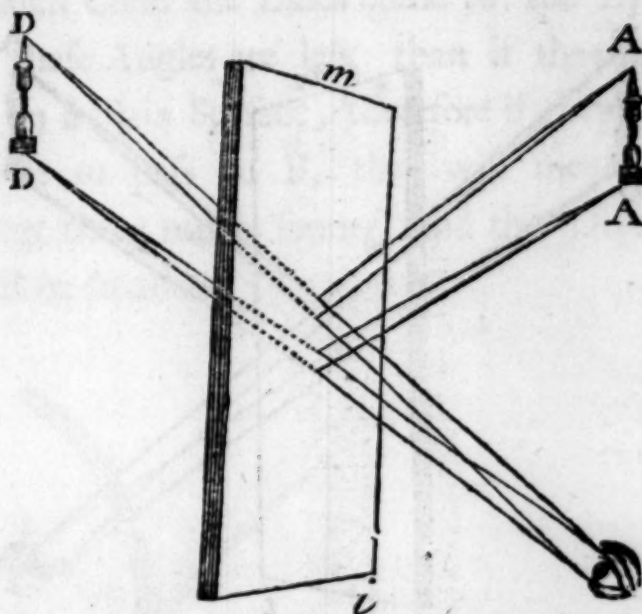
The Rays from every Point of the Object A, in Cones begin to diverge A the inftant they quit the Object; they proceed to the Surface of the Glafs : there each of thofe Rays falls, difperfes, and is reflected towards the Eye. The Eye carries them back to the Points D D, at the end of the right Lines, where the fame Rays would meet; but in meeting at the Points D D, thofe Rays act in the fame manner, as at the Points A, A, where they begin to fpread; therefore you fee the Object A A at the Points D D.

Thefe Angles and Lines ferve no doubt to make us underftand this Artifice of Nature;

E   but
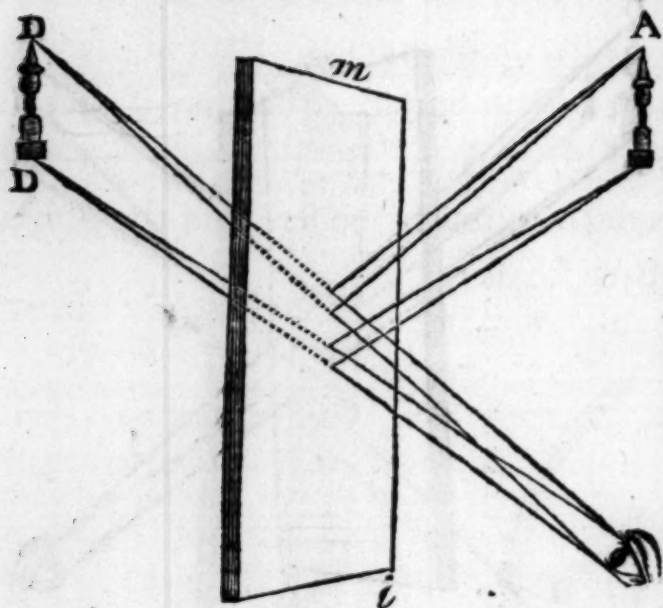
but they are far from informing us of the Phyfical Efficient Caufe, why the Soul without hefitating carries the Object as far beyond the Glafs as it is on this fide of it. Thefe Lines reprefent what happens, but do not fhew why it happens.

If you would know in what manner a Convex Glafs diminifhes, and a Concave Glafs enlarges Objects, thefe Lines of Incidence and Reflection will give you the fame Reafon.

Convex Looking-Glafs. We are told ; that the Cone of Rays, which diverge from the Point A, and fall on the Convex Glafs, makes Angles of Incidence upon it equal to Angles of Reflection,

of

of which Cone the Lines come to the Eye.
Now these Angles are less, than if they had
fallen on a plain Surface; therefore if they are
supposed to pass to B, they will meet or
converge there much sooner, and the Object
in B B be smaller.
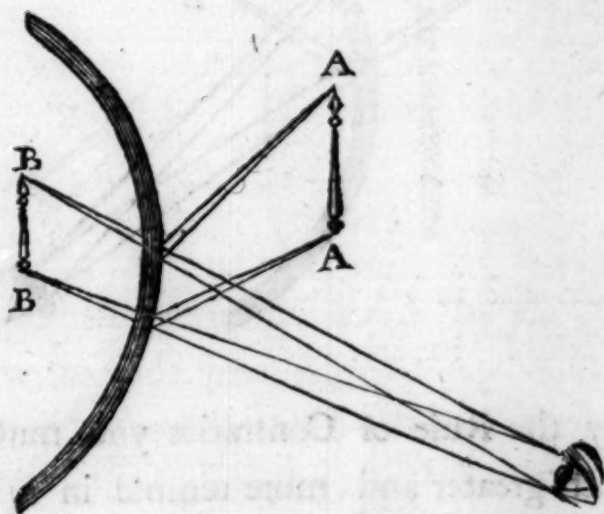
Now the Eye carries the Object to B B in
Points, from which the Rays begin to di-
verge, therefore the Object must appear less,
as it does in the above Figure. For the same
reason that it appears less, it appears nearer,
as the extreme Points of the Rays from B B,
are actually nearer the Glass than those of
the Rays from A A.

E 2　　　　　　　By
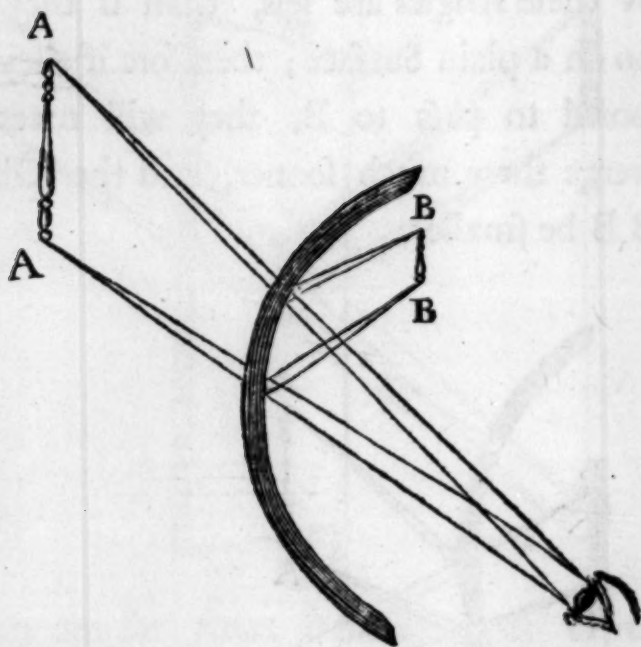
Concave   By the Rule of Contraries you muſt ſee
Glaſs.   Objects greater and more remote in a Con-
cave Glaſs, when placed near enough to the
Glaſs.

For the Cones of the Rays from B B, ſpread-
ing upon the Glaſs at the Points where thoſe
Rays fall, if they were reflected thro' that
Glaſs, they would not unite but in A A,
therefore they are ſeen in A A. Now A A
is greater and morere mote from the Glaſs
than B B, and therefore we ſee the Object
greater and farther off.

This

This is in general what happens in the ... Rays to our Eyes; and all the ... ... anomalies are founded on this ... Principle, that the Angle of Incidence is ... equal to the Angle of Reflection.

We are now to enquire in what manner ... distinct Vision, more or lesser Di-... ... and justly why Objects, that prime ... ... reverted to our Eyes, should ... moved to them as they are.

... accord. to *Mathesios* and *Opticians*, the Common ... Mathematicians inform us that the greater or ... the Angle in which an Object appears in the ... ... appears its ... ... magnitude of objects ... ... is wide enough? These ... ... an ... ... appeared Dimensions an Angle, as that for the ... ... Eye A (... ...) at two hours at Paris ... ... another ancient, as by one half or another ... ... and at B before the A ... ... as one ... ... which the Angle is one ... ... which was the angle of which that Object is ... ... base. These Angles are opposite at ... ... Summits or Vertical Points, therefore ... ... according to the ... Notions of the Ele-... ... of Geometry, they are equal. Hence ... ... the Angle formed in the Eye A, be double ...

E 3 the

This is in general what happens in the Reflection of Rays to our Eyes, and all the Mysteries of Catoptricks are founded on this sole Principle, that the Angle of Incidence is always equal to the Angle of Reflection.

We are now to know in what manner Glasses augment, objects and lessen Distances; and lastly why Objects, that paint themselves reversed in our Eyes, should however be seen as they are.

In regard to Magnitudes and Distances, the Mathematicks inform us, that the greater the Angle is, which an Object makes in the Eye, the greater the Object will appear: nothing is more plain. The Line H K at an hundred Paces forms an Angle, as you see in the Eye A (Figure 1;) at two hundred Paces, it forms another less by one half in another Eye at B. Now the Angle formed on the *Retina,* or of which the *Retina* is the Base, is as the angle of which the Object is the Base. These Angles are opposite at their Summits or Vertical Points; therefore, according to the first Notions of the Elements of Geometry, they are equal. Hence if the Angle formed in the Eye A, be double

The Geometric Explication of Vision.

E 3   the

the Angle formed in the Eye B, the Object will appear as large again to the Eye A, as to the Eye B.

Now, that the Object may be seen as large by the Eye at B, as by the Eye at A, it is necessary to act in such a manner, that the Eye B, may receive as large an Angle as the Eye A, which is as near again to it. The Glasses of a Telescope produce this Effect.

For the greater Facility let us suppose here only one Glass, and abstract from the Effects of many Glasses. The Object H K (Figure 2) transmits its Rays to this Glass, which are united at some distance from it. Let us conceive a Glass so contrived, that those Rays cross one another in such a manner, as to form in the Eye C, as great an Angle as that in the Eye A. The Eye then, you will say, judges by that Angle. It sees the Object of the same Magnitude as the Eye in A. But in A it sees it at the distance of an hundred Paces: therefore in C receiving the same Angle, it will still see it at the same Distance. The whole Effect of multiplied Glasses, different Telescopes, and Microscopes, which magnify Objects, consists therefore

fore in bringing Things to the Eye in a greater Angle. The Object A B, is seen by the means of a Glass in the Angle D C D, which is much greater than the Angle A C B.
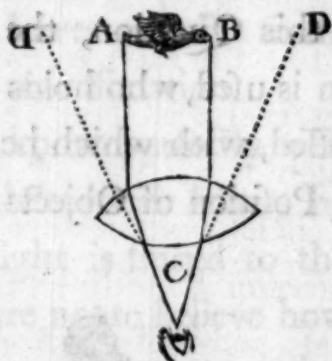
You ask the Rules of Opticks again, why Objects, which are painted reversed upon our *Retina*, are seen in their true Situation.

The Ray from the Head of the Man A, falls upon the lower Point of the *Retina* A, his Feet B are seen by the Rays B B, at the upper Part of the *Retina* B.
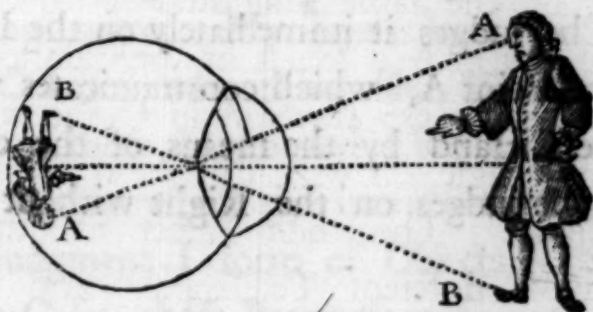
E 4   Thus

Thus the Man is really painted with his Head downwards and his Feet upwards at the bottom of our Eyes. Why therefore do we not see this Man reverfed, but upright and as he is?

To refolve this Queftion, the comparifon of a blind Man is ufed, who holds in his Hand two Sticks croffed, with which he gueffes very rightly of the Pofition of Objects :

For the Point B which is on the left, being felt by the Right Hand with the help of the Stick, he judges it immediately on the Left; and the Point A, which communicates with his Left Hand by the means of the other Stick, he judges on the Right without miftake.

All

All the Masters of Opticks tell us therefore, that the lower part of the Eye, immediately transfers its Sensation of the Object to the upper part A, and that the upper part of the *Retina*, as naturally transmits its Sensation to the lower part B, so that the Object is seen in its true Situation.

When we know perfectly well all the Angles and Mathematical Lines, by which the Passage of Light is traced to the bottom of the Eye, we are not to believe however that we know in what manner we attain our Perceptions of the Magnitudes, Distances, and Situations of Things. The Geometrical Proportions of those Angles and Lines are just indeed; but there is no more relation between them and our Sensations, than between the Sound we hear, and the Magnitude, Distance, and Situation of the Thing heard. My Ear is struck by Sound; I know the Notes and nothing more. My Eye is kept by Sight, I see Colours and nothing else. The Proportions of those Angles and Lines cannot only be in any respect the immediate Cause of the Judgment I form of Objects; but in many Cases, those Proportions do not in the

least

leaft agree with the manner in which I fee Objects.

For Inftance, we fee a Man of the fame Size at four and eight Paces from us *. And yet the Image of that Man at four Paces is exactly twice as large in the Eye as at eight. The Angles are different; the Object is however of the fame Dimenfions; it is evident therefore from this fingle Example, out of many, that thefe Angles and Lines are far from being the immediate Caufe of the manner in which we fee.

Before therefore we purfue the Enquiries we have begun upon Light, and the Mecha-nick Laws of Nature, it is your Command, that I fhould here fhew in what manner the Ideas of Diftances, Magnitudes, Situations, and Objects, are imparted to the Soul. This Enquiry will fupply us with fome new Truths, which is the only excufe for a Book.

* We judge him to be of the fame Size, but do not fee him fo.

C H A P.

CHAP. VI.

In what Manner we know Distances,
Magnitudes, Figures, and Situa-
tions.

LET us begin with Distance. It is plain
that it cannot of itself be immediately
perceived ; for Distance is no more than a
Line from an Object to us. This Line ter-
minates in a Point, we therefore perceive
only this Point ; and whether the Object be
a thousand Miles or only a Foot from us,
the Point is still the same.

We have not therefore any immediate
Means of knowing Distance instantly, as
we have by the Touch, of distinguishing
whether a Body be hard or soft ; by the
Taste, whether it be sweet or bitter ; and by
the Ear, whether of two Sounds the one be
grave and the other acute. The Idea of
Distance therefore must be attained by the
Means of some other intermediate Idea ; but I
must at least have that intermediate Idea the
same time ; for an Idea that I have not, will cer-
tainly

Distance
not known
from the
Angles and
Lines of
Opticks.

tainly never occafion my having another.　I
fay fuch a Houfe is a Mile from fuch a Ri-
ver; but if I don't know where that River
is, I certainly don't know where the Houfe
is.　A Body that eafily receives Impreffion
from my Hand I conclude foft; another re-
fifts, I immediately perceive its Hardnefs; it
were therefore neceffary, that I perceived the
Angles formed in my Eyes, in Order to de-
termine immediately the Diftances of Ob-
jects from them.　But nobody ever thinks of
thefe Angles in looking at an Object.　Moft
Men do not fo much as know that there are
fuch : It is evident then thefe Angles cannot
be the immediate Caufe from which we know
Diftances.

Proved by in Exam-ple.　The Perfon who the firft Time of his
Life fhould hear the Report of a Cannon, or
the Harmony of a Concert, would not be
able to judge whether that Cannon were dif-
charged, or that Concert executed, at the
Diftance of a League or at that of thirty
Paces.　Only Experience can accuftom him
to judge of the Diftance between him and
the Place from whence thofe Sounds come.
The Vibrations, the Undulations of the Air,

bring

bring Sounds to his Ears, or rather to his
Soul, but it apprizes his Soul no more of the
Place where the Sounds began, than it in-
ftructs him in the Form of the Cannon, or
of the Inftruments of Mufick.

It is exactly the fame Thing with Refpect
to the Rays of Light tranfmitted by an Ob-
ject, they do not inform us at all how far
that Object is.

They leave us no lefs in the Dark with *Magni-*
Regard to Magnitudes, and even Forms or *tudes and*
Figures. *Figures not*
known by
thofe optick
I fee at a great Diftance a Kind of little *Lines.*
round Tower. I go on, I perceive, and
touch a great quadrangular Building. Cer-
tainly what I fee and touch, is not what I
faw before. The little round Object which
I had in my Eye, is not this great fquare
Building.

The meafurable and tangible Object there-
fore is one Thing, and the Object of Vifion
another. I hear in my Chamber the Noife *Proved by*
of a Coach : I open my Window and fee it; *an Exam-*
ple.
I go down and get into it. Now this Coach,
which I have heard, this Coach which I
have feen, and this Coach I have touched, is

three

three abfolutely different Objects of three of
my Senfes, which have no immediate Rela-
tion to each other.

But farther; it is demonftrated, as I have
faid before, that there is an Angle in my
Eye twice as large, when I fee a Man at four
Feet from me, as when I fee the fame Man
at eight. However, I always fee this Man
of the fame Size: Whence is it, that my
Perception contradicts the Mechanifm of my
Organs in this Manner? The Object is real-
ly as fmall again in my Eyes, and I fee it
twice as large as it is. It is in vain to think
of explaining this Myftery by the Paffage
through the Cryftalline, or the Form that
Humour takes in our Eyes. Whatever Sup-
pofition we may make, the Angle in which
I fee a Man at four Feet from me, is al-
ways twice as large as the Angle in which I
fee him at eight; and Geometry will never
folve this Problem.

Nor the Si-
tuation of
Objects.

These geometrical Lines and Angles are
not more really the Caufe that we fee Ob-
jects in their Places, than that we fee them
of fuch Magnitudes, and at fuch Diftances.

The

The Soul does not confider whether fuch a Part is to paint itfelf at the Bottom of the Eye, it's not concerned with Lines it does not fee. The Eye only turns itfelf downwards to fee what is near the Earth, and upwards to look at what is above it.

All this could only be explained, and made inconteftible by fome Perfon born blind, and reftored to the Senfe of Sight. For if this blind Perfon, at the Moment he received Sight, had judged of Diftances, Magnitudes, and Situations, it had been true that the optick Angles, formed that in-ftant in his *Retina*, had been the imme-diate Caufes of his Thoughts. Dr. *Barclay* accordingly has affured us, after Mr. *Locke,* (and indeed has gone beyond Mr. *Locke* in this Point) that neither Situation, Magni-tude, Diftance, nor Figure, would be at all difcerned by a blind Perfon, at the Inftant his Eyes fhould receive Light.

But where was the blind Perfon to be found, on whom the indifputable Decifion of this Queftion depended. In the Year 1729, Mr. *Chifelden,* one of thofe famous Surgeons, who unite a great Extent of

Proof by an Expe-riment on a Perfon born blind, cured by Mr. Chi-felden.

Knowledge

Knowledge with Dexterity in Operations, having imagined, that Sight might be given to a Person born blind, by removing the Cataracts, which he conceived to have been formed in his Eyes almost at the Moment of his Birth, he proposed the Operation. The blind Person made Difficulties to consent to it. He could not very well conceive, that the Sense of Sight could contribute much to his Happiness. Without inculcating to him the its use for learning to read and write, he had never desired to see. His Indifference in this Point proves, that *It is impossible to be unhappy by the Privation of the Good of which we have no Idea.* A very important Truth. However that be, the Operation was performed and succeeded. The Youth then about fourteen Years of Age, saw the Light for the first Time. This Experiment confirmed all that *Locke* and *Barclay* had therein rightly foreseen. For a long Time he distinguished neither Magnitude, Distance, Situation, nor even Figure. An Object of an Inch placed before his Eyes, that concealed an House from his Sight, appeared to him as big as the House. Every Thing he saw,

<div align="right">seemed</div>

seemed at first to be upon his Eyes, and to touch them, as the Objects of the Sense of Feeling touch the Skin. He could not distinguish what he had judged round, by the Help of his Hands, from what he had judged square; nor discern with his Eyes, whether what his Hands had perceived to be above or below, were really above or below. He was so far from knowing Magnitudes, that after having at Length conceived by Sight, that his House was larger than his Chamber, he could not conceive how Sight could give him that Idea. He could not perceive, till after two Months Experience, that Pictures only represented solid Bodies, and when, after so long a Trial of his new Sense, he had thought, that Bodies, and not Surfaces only, were in the painted Tables, he applied his Hand to them, and was amazed that he did not feel those solid Bodies, of which he began to perceive the Representations. He asked which of the Senses deceived him, that of Feeling, or that of Seeing.

This was an indisputable Decision, that the Manner in which we see Objects, is no

F immediate

immediate Confequence of the Angles formed
in our Eyes ; for the fame mathematical
Angles were in the Eyes of this Youth, as
well as in ours, and were of no Manner of
Ufe to him without the Aid of Experience,
and the other Senfes.

In what Manner we know Magnitudes and Diftances.

In what Manner then do we reprefent
Magnitudes and Diftances to ourfelves?   In
the fame as we imagine the Paffions of Men,
by the Colours which thofe Paffions paint in
their Faces, and the Alteration they make in
their Features.   There is nobody who does
not immediately read Shame or Anger in
another's Countenance.   This is the Lan-
guage which Nature fpeaks to every Eye;
but a Language to be learnt only by Expe-
rience.   It is Experience only that alfo teach-
es us, that when an Object is too remote,
we fee it confufedly and faintly :   From
thence we form Ideas, with which the Sen-
fation of Sight is ever after attended.   Thus
every Man, who, at the Diftance of ten
Paces, has feen a Horfe five Foot high,   if
he fees, fome Minutes after, the fame Horfe
no bigger than a Sheep, his Mind, by an invo-
luntary Judgment, concludes immediately that
the Horfe is a great Way off.   It

It is certain, that when I see my Horse so small as a smaller Image, a more acute Angle is formed in my Eye ; but that is what attends, not what causes, my Thought.

This Angle is so far from being the immediate Cause that I judge an Horse very far off when he seems very little ; that every Moment I see the same Horse of equal Size at ten, twenty, and thirty Paces from me, tho' the Angle is double, triple, and quadruple at those different Distances.

In like Manner my Brain is affected differently, when I see a Man red with Shame, and when I see him red with Anger ; but those Impressions would suggest nothing to me of what passes in the Soul of that Man, without the Language of Experience, which alone imparts it to me.

I see a great Way off, through a little *Example.* Hole, a Man upon the Top of a House, the Distance and small Number of Rays prevent me from distinguishing at first whether it be a Man or not : The Object seems very small, and I take it for a Statue of two Feet at most : The Object moves, I conclude it a Man, and from that Instant he is thought

to be of the ufual Stature ; from whence proceed two Judgments fo different ?

When I believe I fee a Statue, I imagine it two Feet high, becaufe I fee it in fuch an Angle : No Experience inclines my Thoughts to contradict the Rays impreffed upon my *Retina** ; but as foon as I judge it a Man, the Connection implanted in my Brain by Experience between the Idea of a Man and the Idea of an Height from five to fix Feet, obliges me, without thinking of it, to imagine, by an inftant Judgment, that I fee a Man of fuch a Height.

We learn to fee as we learn to read.

From all this we muft abfolutely conclude, that Diftances, Magnitudes, and Situations, are not, properly fpeaking, Things to be feen, that is to fay, the proper and immediate Objects of Sight.　The proper and immediate Object of Sight is nothing in Nature but coloured Light ; all the reft we only attain to know by Length of Time and Experience. We learn to fee, exactly as we learn to fpeak and read. The Difference is, that the Art of Seeing is the moft eafy, and that we are all equally Nature's Pupils in learning it.

* Yes, the feeing it confufedly and faintly, tells me it's far off, and therefore bigger. *See* p. 66. l. 17.

The

The sudden and almost uniform Judgments, which every Mind forms at a certain Age of Distances, Magnitudes, and Situations, makes us think it only necessary to open the Eyes, in order to see Things as they are. But this is a Mistake; the Aid of the other Senses is essential to this Effect. If Men had no other Sense but that of Sight, they would have no Means of knowing Extent, Length, Breadth, and Depth*; and a pure Spirit or Angel could never know it, unless God revealed it to him. It is very difficult to separate in our Understanding the Extension of an Object from the Colours of it. We never see any Thing that is not extended, and from thence are all led into the Belief, that we actually see Extent. We can scarce distinguish in Thought the Yellow, which we see in a Piece of Gold, from the Piece of Gold of which we see the Yellow. Thus when we hear the Word a *Guinea* pronounced, we cannot help annexing the Idea of that Coin to the Sound we hear uttered.

If all Men spoke the same Language, we should always be ready to believe, that there

* Except relatively, but not really without Feeling.

F 3

would

would be a neceffary Connection between
Words and Ideas.   Now in this Point all
Men have the fame Language, with Refpect
to Imagination.   Nature tells it to all that
when you have feen Colours for a certain
Time, your Imagination will reprefent to
you, in the fame Manner, all the Bodies, in
which thofe Colours feem inherent.   That
fudden and involuntary Judgment, which
you fhall form, fhall be ufeful to you du-
ring the Courfe of your Lives; for if, to
judge of the Diftances, Magnitudes, and Si-
tuations of all that furrounds you, it were
neceffary to wait till you had examined the
Angles and Rays of Vifion, you would die
before you knew, whether the Things
you had Occafion to ufe, were at the Dif-
tance of ten Paces from you, or at that of
an hundred millions of Leagues, whether
they were of the Bignefs of a Mite or a Moufe.

We are therefore very much in the wrong
when we fay our Senfes deceive us *. Each of
them difcharge the Function for which Na-
ture intended them.   They affift each other
mutually, in conveying to the Soul by the

* We fuffer ourfelves to be directed by our Senfes.

Means

Means of Experience, such a Measure of Knowledge as our Condition admits. We demand of our Senses, what they were not formed to bestow. We are for knowing from our Eyes Solidity, Magnitude, Distance, &c. but the Touch must unite in this with the Sight, and Experience with both. If *Mallebranche* had considered Nature in this View, he had ascribed fewer Errors to our Senses, which are the sole Springs of all our Ideas.

It is Time to resume the Thread of *Newton's* Discoveries, and to return to our physical and mathematical Enquiries.

F 4   **C H A P.**

CHAP. VII.

Of the Cause of the breaking of the Rays of Light in passing from one Medium to another; that this Cause is a general Law of Nature unknown before Newton; *that the Inflection of Light is also an Effect of the same Cause.*

WE have already seen the almost incomprehensible manner, in which the Reflection of Light is performed, and which the known Impulsion cannot cause. That of Refraction, of which we are now going to resume our Examination, is no less surprizing.

What Refraction is. Let us begin by establishing in ourselves a clear Idea of the Thing we are to explain. Let us remember well, that when Light falls from a more rare and thin Medium, as the Air, into one more heavy and dense, as the Water, which in appearance should resist it more than the former, that then Light quits its Course or Direction, and breaks in a Line

approach-

approaching to a perpendicular raised upon the Surface of that Water.

Mr. *Le Clerc*, in his Physicks, has said directly the contrary for want of Attention. In the Eighth Chapter of his Fifth Book he says; " The greater the Resistance of Bodies " is, the more the Light that falls into them " removes from a Perpendicular. Thus a " Ray removes from a Perpendicular in pas- " sing from the Air into Water." This is not the only Mistake in *Le Clerc*, and a Man who should have the Misfortune to study Physicks in the Writings of that Author, would scarce have any but false and confused Ideas.

To have a perfectly clear Idea of this Truth, observe the Ray A, E which falls from the Air into this Crystal.
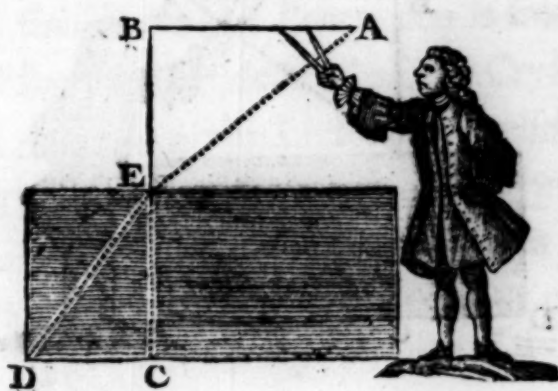
You know in what manner it is broke; The Ray A E makes an Angle with the Perpendicular B E, in falling upon the Surface of the Cryſtal. The ſame Ray refracted in the Cryſtal makes another Angle with the ſame Perpendicular, which determines its Refraction. It was neceſſary to meaſure this Incidence and breaking of Light. *Snellius* firſt found the perpetual Proportion, according to which the Rays are broke in different Mediums. The Honour of it was aſcribed to *Deſcartes.* People always aſcribe to the Philoſopher of greateſt Reputation the Diſcoveries he publiſhes: he improves by the Labours of the obſcure, and augments his own Glory by their Enquiries. The Diſcovery of *Snellius* was a Maſter-piece in his Time. That Proportion is very intelligible.

The
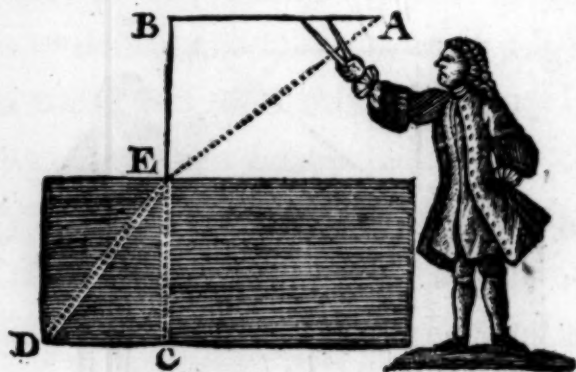
The greater Line A B, which you see, is, the greater also will be the Line C D. The Line A B is called the *Sine* of Incidence. The Line C D is the *Sine* of Refraction. This is not a proper Place to explain in general what a *Sine* is. Those who have studied Geometry know it already. Those who have not, might find some difficulty in the Definition of it. It suffices to understand aright, that these two *Sines*, of whatsoever Extent they be, are always in Proportion to one another according to the Medium.

The Light, which falls obliquely from the Air into the Cryftal, is broke there in such a manner, that the *Sine* of Refraction C D is to the *Sine* of Incidence A B, as 2 is to 3 *, which is no more than to say, that the A B is one third greater in the Air, in this Case, than the Line C D is in the Cryftal.

In the Water this Proportion is from 3 to 4. Hence it is evident, that the Cryftal refracts, or breaks, the Light one twelfth more strongly than Water. Consequently in all Cases, and in all possible Obliquities of In-

* This is true on Supposition that A E and E D were equal, then C D and A B would be Sines of the two Angles to one Radius.

cidence,

cidence, Cryftal will be more refracting than Water by a twelfth. The Queftion is to know not only the caufe of Refraction, but the caufe of different Refractions.

Defcartes, according to his Cuftom, has invented ingenious and plaufible Reafons for this Property of Light; but in this, as well as the reft, fetting his Wit in the Place of Reality, he has given us Conjectures inftead of Truths. He tells us that Light, in paffing from the Air into a new, more denfe, and compact Medium, paffes more freely in it, and is lefs retarded in its pretended Tendency to Motion, and *lefs retarded,* fays he, *lefs interrupted in a denfe Medium, as Glafs, than in a thinner Medium, as Water.* We have already feen how much he impofes upon himfelf in afferting, that Light has only a Tendency to Motion. We have feen, that the Rays actually move, becaufe they change their Place before our Eyes in their Refractions. But his Error here is ftill farther important: He deceives himfelf in believing,

that thofe Bodies which break the Light moft, are always the moft folid in which the Paffage of Light is more eafy. It

is

is not true, that all folid Bodies abfolutely re-
fract Light more than fluid Bodies ; for tho'
in Effect Water does not occafion fo ftrong
a Refraction abfolutely fpeaking, as Glafs ;
however, in regard to its Denfity, it occa-
fions a ftronger.   It is certain that Light is
broke a twelfth more in Glafs than in Water;
but if Refraction were determined in Pro-
portion to Denfity, it ought much to exceed
a twelfth in Glafs.   Imagine two Men, the
one four times ftronger than the other.   If
the ftronger carry only a Weight twice as
heavy as the weaker, we fhould fay with *Proof.*
Truth, that in regard to his Strength, he
does not carry fo much as the other by a
great deal ; for he ought to carry four times
as much.

Amber refracts much ftronger in Propor-
tion to its Denfity.   Can one fay however,
that Amber opens a more eafy Paffage for
Light than Cryftal ? It is therefore a falfe
Suppofition, *that Light is broken in a Line
approaching to a Perpendicular, when it enters
a more folid, tranfparent Body, which refifts it
the lefs, becaufe it is more folid.*

3   **Obferve**

Obferve that every Experiment and Calcu-
lation deftroys almoft all the Ideas of *Def-
cartes*, when that great Philofopher found
them only upon Hypothefes.   They are fhin-
ing and delufive Profpects, which diminifh in
Proportion as we approach them.   All the
reft of the Philofophers have endeavoured at
Solutions of this Problem of Nature;   but
Experience has alfo refuted their Conjectures.

Miftake of other great Philofo- phers upon this Head. *Barrow* taught, after Father *Defchalles*,
that the Refraction of Light, in approaching
to a Perpendicular, was occafioned *by the Re-
fiftance of the Medium*; that *the more a Me-
dium refifted the Paffage of Light, the ftronger
that Refraction became.*

This Idea was the Reverfe of that of *Def-
cartes*; and only proved, that there are diffe-
rent ways to Error.   They had only to con-
fult Experiments; they had only to meafure
the Refractions made in Spirits of Wine,
which are much greater than in Water;
they had only to confider, that Spirits of
Wine undoubtedly do not refift more than
Water, and that however they occafion
a Refraction as ftrong again; and they would
then have corrected this fmall Error.   And
indeed

indeed Father *Deschalles* owns, that he very much suspects his own Doctrine.

At length *Newton* alone discovered the true Reason enquired after. His Discovery undoubtedly merits the Attention of all Ages. For the Question here does not only regard a particular Property of Light, tho' that were a great Point ; we shall see that this Property extends to all the Bodies in Nature.

Newton's *great Discovery.*

Consider that the Rays of Light are in Motion, that if they turn aside in changing their Course, it must be an Effect of some Primitive Law, and that, nothing should happen to Light, but what should happen to all other Bodies of the same smalness as Light, *cæteris paribus.*

Let a Ball of Lead A move obliquely from the Air into the Water, the contrary of what happened to the Ray of Light will happen to the Ball ; for that a subtile Ray enters into the Pores of the Water, and the Ball, whose Superficies is large, encounters the Superficies of the Water which buoys it up.

This
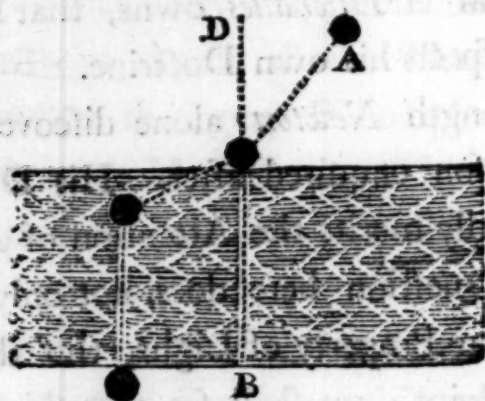
This Ball removes then at first from the Perpendicular D B; but when it has entirely lost the oblique Motion impressed upon it, it is left to itself, and falls directly in a perpendicular Line, from the Point where it began to sink. Now *Newton* has discovered and proved, that there is a Power in Nature, which makes all Bodies tend towards each other in a strait Line, in direct Proportion to their Quantity. This Power therefore (such as it may be) must act in the Water upon a Ray, and the Quantity of the Ray being incomparably less than that of the Water, the Ray must be sensibly moved towards it.

Observe then this Ray of Light, which falls perpendicularly from the Air upon the Surface of this Crystal. As

B
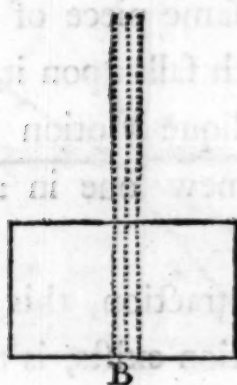
As this Line falls perpendicularly, the Power of Attraction, such as it is, acting in a right Line, the Ray does not turn aside from its Course; but arrives more swiftly than it would have done in B; and this is another Truth discovered by *Newton*.

Before him, this Ray of Light was believed to be retarded in its Course by entring into the Water. On the contrary, it enters it with additional Force. But why? Because it falls into it both by its own Motion, and by that which the Attraction of the Water, or the Glass, impresses upon it. This Ray arrives more swiftly in B, by this accelerative Force, than it would have passed through the Air without it.

G   But

But if we confider in the fame Bafon of Water, or the fame piece of Glafs, the oblique Ray which falls upon it, what follows? It retains its oblique Motion in a right Line, and acquires a new one in a perpendicular Line *.

That this Attraction, this Tendency, this kind of Gravitation exifts, is not to be doubted: for we have feen Light, attracted by Glafs, re-enter it without touching any Thing; now this Power neceffarily acts in a perpendicular Line, that Line being the fhorteft way.

As this Power exifts, it exifts in all the Parts of Matter. The Parts of the Superficies of every Body whatfoever, do exert therefore this Power, before the Ray enters or attains the Center to which it is directed. Thus as foon as this Ray arrives near the Superficies of the Cryftal or the Water, it begins to incline a little in this manner towards a Perpendicular.

* Two Forces acting on it the fame Time in different Directions, it takes a Courfe between them.

It
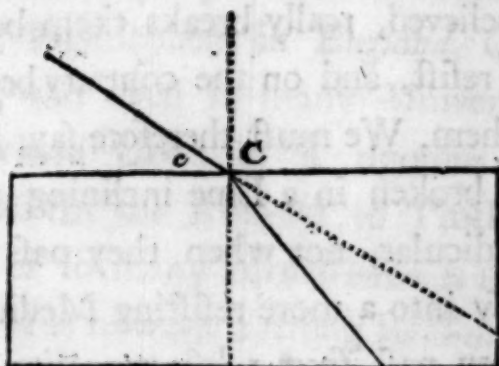
It begins to break a little in c, before it
enters : the farther it goes, the more it
breaks; that is, the nearer Bodies are the
more they attract each other, and that which
is more in Subſtance determines that which is
leſs towards it. Thus the ſame happens to
this Ray of Light as to every other Body
that has two different Directions; it is en-
groſſed by neither, but holds a Courſe that
participates of both. This Ray therefore
neither falls entirely in a perpendicular Line,
nor follows its firſt oblique Direction, in paſſing
thro' the Water or the Glaſs; but it follows
in a Line, which participates of both, and
which deſcends the faſter, in Proportion to
the Force with which the Water, or Cry-
ſtal, attract it. The Water therefore, far from

break-

breaking the Rays of Light by refifting them, as was believed, really breaks them becaufe it does not refift, and on the contrary becaufe it attracts them. We muft therefore fay, that the Rays are broken in a Line inclining towards a Perpendicular, not when they pafs from a more eafy into a more refifting Medium, but when they pafs *from a lefs attracting, into a more attracting Medium.* Obferve, that this Word *attracting* muft never be underftood, but as towards the Point to which that known Power, an indifputable Property of Matter, directs itfelf.

You are fenfible, that abundance of People, as much attached to the Philofophy, or rather the Name, of *Defcartes*, as they were formerly to the Name of *Ariftotle*, have declared againft Attraction. Some would not ftudy it, others defpifed and condemned it, after having fcarce examined it; but I beg the Reader to make the three following Reflections.

The Word Attraction fhould be examined before declared againft.

1. What are we to underftand by Attraction? Nothing but a Force by which one Body approaches another, without any other Force being feen or known to impel.

2

2. This

2. This Property of Matter is received by the beſt Philoſophers in *England, Germany, Holland,* and even in many Univerſities of *Italy,* where Laws of a rigorous Nature ſometimes bar the Avenues to Truth. The Conſent of ſo many learned Men is no Proof indeed ; it is however a ſtrong Reaſon for examining at leaſt, whether this Power exiſts or not.

3. We ought to ſuppoſe, that we know no more of the Cauſe of Impulſion, than we do of that of Attraction. We even have not a greater Idea of the one than the other of theſe Powers; for no-body can conceive why a Body has Power by them to move another from its Place. Neither, indeed, do we conceive better why the Parts of Matter gravitate towards each other. *Newton* himſelf did not pretend to know the Reaſon of this Attraction. He has only proved its Exiſtence: he ſaw a conſtant Phænomenon, an univerſal Property in Matter. If a Man diſcovers a new Metal in the Earth, would this Metal exiſt the leſs, becauſe the firſt Principles of it were not known. Let the Reader of this little Treatiſe peruſe Mr. *Maupertius*'s Metaphyſical Diſcuſſion upon Attraction, in the

G 3 ſmalleſt

fmalleft and perhaps beft wrote Philofophical Book in *French*. He will there fee thro' the Referve with which the Author explains himfelf, what he thinks, and what is to be thought of Attraction, of which the Name has given fo much Offence.

We have feen in the fecond Chapter, that the Rays of Light reflected to us from a Looking-Glafs cannot be reflected from its Surface. We have feen experimentally, that the Rays, tranfmitted by a Glafs to a certain Angle, return inftead of paffing into the Air; that, if there be a Void behind that Glafs, the Rays which were tranfmitted before, return from that Void to us. In this Cafe there is certainly no Impulfion. Another Power muft neceffarily be admitted; and at the fame time we muft inevitably admit, that there is fomething in Refraction hitherto not underftood.

Now what Power is that, which breaks a Ray of Light in a Bafon of Water? It is demonftrated, (as we fhall fhew in the following Chapter) that, what had hitherto been believed a fingle Ray of Light, is a Groupe of many Rays, which are all differently refracted.

ed. If one of the Rays of Light contained in this Groupe is refracted, for Instance, at four Degrees distance, another will be at three, from a Perpendicular. It is demon- *Proofs of* strated, that the most refrangible, that is to *tion.* say, those which in being broke on quitting the Glass, and in taking a new Direction in the Air, go most from the Perpendicular of that Glass, are also those which are reflected soonest and with most Ease. It is therefore already very probable, that the same Law which occasions the Reflection, occasions also the Refraction of Light.

Lastly, If we find still some new Property of Light, which appears to derive its Origin from the Force of Attraction, ought we not to conclude that so many Effects proceed from the same Cause?

This new Property was discovered by Father *Grimaldi* the Jesuit about the Year 1660, upon which *Newton* has carried his Enquiries so far as to measure the Shadow of an Hair at different Distances. This Property is the Inflection of Light. The Rays not only break in passing the Medium, the Substance of which attracts them; but other Rays,

G 4 which

which pass in the Air near the Edges of the attracting Body, sensibly approach it, and visibly turn aside from their Course or Direction. Put a Blade of Steel or thin Glass ending in a Point, in a dark Place: let it be set near a little Hole through which the Light passes; and let the Light almost touch the Point of this piece of Steel or Glass.

The Rays will bend in such a manner near it, that the Ray next the Point will be more curve, and the farthest from it less so in proportion. Is it not highly probable, that the same Power, which breaks these Rays, when in this Medium, forces them to incline towards it, and quit their Direction, when they are near it? Thus we see Refraction, Transparence, and Reflection subjected to new Laws; and an Inflection of Light resulting evidently from Attraction. Thus a new Universe presents itself to the Eyes of those who are willing to see it.   We

We shall soon shew, that there is an evident Attraction between the Sun and the Planets, and a mutual Tendency of all Bodies towards each other. But we think proper to observe here, that this Attraction, which causes the Gravitation of the Planets towards the Sun, does not at all act in the same Ratio's, as the Attraction of Corpuscles which touch each other. We must also remember well, that those Ratio's change at the Point of Contact; and not believe, that Light is inflected towards the Cryftal and in the Cryftal in the same Ratio, for Instance, as Mars is attracted by the Sun. All Bodies, as we shall see, are attracted in the Ratio inverse of the Squares of their Distances; but at the Point of Contact, they are attracted in the Ratio inverse of the Cubes of their Distances, and even considerably more. Thus Attraction is much stronger, and the Force of it dispersed with much greater Velocity; and this Attraction of Bodies, that touch each other, still augments in Proportion to the smallness of the Bodies. Thus the Particles of Light, attracted by the small Substance in Glass, are far from following

the

the Laws of the Planetary Syſtem. Two Atoms, and two Planets, as Jupiter and Saturn, are governed by Attraction; but by different Laws of Attraction. This is what we ſhall explain in our laſt Chapter but one, and which we thought proper to premiſe here to remove all Ambiguity.

C H A P.

CHAP. VIII.

The wonderful Effects of the Refraction of Light. The several Rays of Light have all possible Colours in themselves ; what Refrangibility is. New Discoveries.

IF you ask the Philosophers what is the *cause* of Colours, *Descartes* will tell you, *That the Globules of his Elements are determined to turn round upon themselves with Velocity, besides their Tendency to Motion in a right Line, and that these different Whirlings round are the cause of different Colours.* But, in reality, what are his Elements, his Globules and Whirlings, do they require the Touchstone of Experiment to prove them false ? A multitude of Demonstrations annihilate these Chimera's, of which the following are most simple and sensible,

Dispose a number of Balls against one another ; suppose them pushed and turning about with Velocity on all sides, the very Words shew, that it is impossible for these

Imagination of Descartes in respect to Colours.

con-

contiguous Balls to move forward regularly in
right Lines.   Again in what manner should
we fee this Point Blue and this Point Green
upon a Wall ?
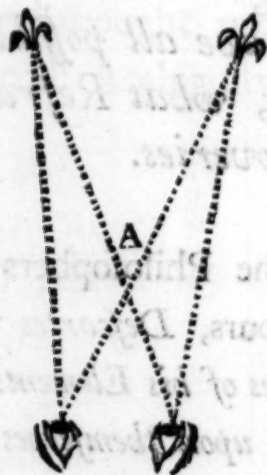
Suppofe them marked on this Wall ; they
muft crofs each other at the Point A, before
they reach our Eyes.   As they crofs each o-
ther, their pretended Whirling muft change
at the Point of Interfection.   The Whirlings
of the Blue and the Green fubfift then no
longer as before ; in Confequence there would
be no longer either the Point Green or the
Point Blue.   A *Flemifh* Jefuit made this Ob-
jection to *Defcartes.*   The latter was fenfible
of all its Force, but could one have imagin-
ed he would anfwer ; *That thofe Balls do not*
                                        actually

actually turn round, but that *they have a Tendency to turning round?* This *Descartes* says in his Letters. The Act of *transparent, quatenus transparent,* is it more intelligible?

You will tell me, without doubt, that there is the same Difficulty in all Systems: that the Rays from the Point Blue and the Point Green necessarily cross each other, whatever Opinion we espouse in respect to Colours; that this Intersection of the Rays must always prevent Vision; in a Word, that it is always incomprehensible, how Rays, which cross each other, should come to our Eyes in their proper Order; but this Scruple will soon be removed, if we consider, that every Part of Matter has incomparably more Pores than Substance. A Ray of the Sun, thirty millions of Leagues in length, has probably not one Foot of solid Matter in its whole Extent. It would therefore be very possible for such a Ray to pass through another in this manner without displacing any thing.

<div align="right">They</div>

They do not only pass in this manner, but over one another like two Staffs. It may further be objected, that the Rays which flow from one Center, do not terminate exactly, and in Mathematical Strictness, at the same Point of the Circumference. That is true : and that Point must always be infinitely small: but two Men never see the same Points of the same Object. This is also true. Of a thousand millions of Persons who should look upon the same Superficies, no two of them would see the same Points.

In the *Plenum* of *Descartes*, it must be confessed, that this Intersection of the Rays is impossible; but every thing is equally impossible in a *Plenum*, and there is no Motion whatsoever that does not suppose and prove a *Vacuum*.

Malle-

Mallebranche in his turn tells us : *It is true* Defcartes *deceived himfelf. His whirling of Globules is not to be maintained ; but they are not Globules of Light, they are little Whirlings of fubtile Matter, capable of Compreffion, which are the caufe of Colours; and Colours confift like Sounds in the Vibrations of that Preffion.* And he adds: *To me it feems impoffible to difcover by any Means the exact Proportions of thefe Vibrations,* that is to fay, of Colours. It is remarkable, that he talks in this manner in the Academy of Sciences in 1699; and that thefe Proportions (or Ratio's) had already been difcovered in 1675; not Proportions of little Whirlings which do not exift; but Proportions of the Refrangibility of the Rays, which forms Colours, as we fhall prefently fhew. What he believed impoffible, was already demonftrated, and what is more, demonftrated to the Eyes, acknowledged true by the Senfes, which would have highly difpleafed Father *Mallebranche.*

Other Philofophers, perceiving the Fallacy of thefe Suppofitions, tell us at leaft with more Probability: *Colours are produced by the Rays of coloured Bodies more or lefs reflected.*

White

*White reflects moft, and Black leaft of them
all. The moft fhining Colours therefore are
thofe which emit moft Rays to the Eye.   Red,
for inftance, which pains the Sight a little,
ought to confift of more Rays than Green, which
gives it moft Eafe.*   This Hypothefis appears
more rational at firft ; but is only Conjec-
ture, (and that too very imperfect and erro-
neous) and a Conjecture is only a new Rea-
fon for enquiring, but not for believing.

*Newton's
Experi-
ments and
Demon-
ftration.*   Let us apply to *Newton.*   He will tell us;
Don't believe me ; believe only your Eyes, and
the Mathematicks : place yourfelf in a Room
entirely darkened, into which the Light comes
only thro' an Hole exceedingly fmall ; the
Ray of Light falling upon Paper will give
you the Colour White.

Place a Prifm of Glafs tranfverfally to a
Ray of Light ; then at the diftance of about
fixteen or feventeen Feet fix the Sheet of
Paper P, oppofite to the Prifm.

You
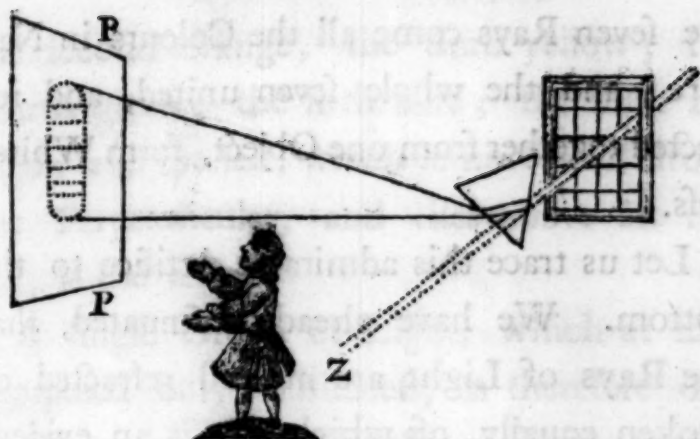
You know already that Light is broke in
entering the Prifm from the Air; you know
that it breaks in a contrary manner in paffing
from the Prifm into the Air. If it was not
broke it would fall from the Hole upon the
Floor of the Room Z. But as this Light in
paffing from the Prifm muft remove from
the Line Z, it will in Confequence ftrike the
Paper. There then appears the whole Se-
cret of Light and Colours. The Ray, which
falls upon the Prifm, is not, as was believed,
a fingle Ray, but a Group, confifting of feven
principal Groups of Rays, each of which car-
ries in itfelf a Primitive or Primordial Colour
peculiar to itfelf *. From that Mixture of

* It's hard to conceive how one Ray can be a Group
or Bundle of Rays containing feven other Bundles; it's
eafier to conceive Rays of feven different kinds falling
mixed on the Prifm that are afterwards feparated by it.

H   the

the feven Rays come all the Colours in Na-
ture; and the whole feven united, and re-
flected together from one Object, form White-
nefs.

Let us trace this admirable Artifice to the
bottom. We have already infinuated, that
the Rays of Light are not all refracted or
broken equally, of which this is an evident
Demonftration to the Eyes*. The feven Rays
of Light having quitted the Body of the
Ray, which is anatomized at paffing from
the Prifm, place themfelves each in its Order,
upon the white Paper, each Ray occupying
an Oval. The Ray which has leaft Force,
Rapidity, and Matter to keep its Direction,
removes moft in the Air from the Perpendi-
cular of the Prifm. That which is the
ftrongeft, moft denfe, and moft vigorous, re-
moves leaft from it. Obferve thefe feven
Rays, which are broke one above another.

Each of them paints upon the Paper the
primitive Colour peculiar to itfelf. The firft
Ray, which removes leaft from the Perpen-
dicular of the Prifm, is the Colour of Fire;

Afceptical Note

* There can be no Demonftration to the Eye, not fo
much for that the Senfe is deceitful, as for that it's doubt-
ful whence that Appearance flows.

H   the

the second orange; the third yellow; the fourth green; the fifth blue; the sixth indigo; and the laſt, which removes moſt from the Perpendicular, and riſes above all the reſt, is the violet.

A ſingle Group of Light, which at firſt *Anatomy of Light.* compoſed only Whiteneſs, is therefore one conſiſting of ſeven Groups of Rays, which have each their peculiar Colour. The aſſemblage of ſeven Primordial Rays therefore is what compoſes white.

If this be ſtill doubted, take a Lenticular Spectacle-Glaſs, which collects all the Rays at its Focus: place this Glaſs upon the Hole at which the Light enters, and you will never ſee any thing at the Focus but a round Spot of white. Place the ſame Glaſs at the Point, where it can collect all the ſeven Rays that paſs thro' the Priſm.

It
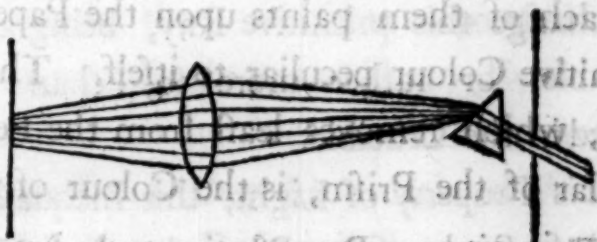
It unites, as you see, thofe feven Rays in its Focus. The Colour of thofe feven Rays is white; which demonftrates that the Colour of all the Rays united is Whitenefs. Confequently the Body which reflects no Light will be black.

For when by the help of the Prifm we have feparated fome of thefe primitive Rays, tho' we make them fall upon a Looking-Glafs, a Burning-Glafs, or another Prifm, they will never change their Colour nor feparate into other Rays. To contain fuch a Colour is their Effence, nothing can alter them more; and as a fuper-abundant Proof, if we take Silk-Threads of different Colours, and lay one of them, a blue one for Inftance at the red Ray, the blue Silk will become red. Put the fame to the yellow Ray it becomes yellow; and fo on with the reft. In fine neither Refraction, Reflection, nor any other Means conceiveable can change this primitive Ray, being as unalterable, or rather more fo, than Gold proved in the Crucible.

Colours in the primitive Rays.

This Property of Light, this Inequality in the Refraction of its Rays, is what *Newton* calls Refrangibility. At firft its Exiftence

was

was oppofed, and continued to be denied a long time, becaufe Mr. *Mariote* had erred in making *Newton*'s Experiments in *France.* People were better pleafed to fay, that *Newton* had boafted of having feen what he had not feen, than to think *Mariote* had not taken proper Methods for feeing the fame, and had not been happy enough in the Choice of his Prifms. Even afterwards, when thefe Experiments had been well made, and Truth had fhewn itfelf to our Eyes, Prejudice ftill fubfifted to fuch a Degree, that in feveral Journals and Books publifhed fince the Year 1730, the fame Experiments are confidently denied, tho' made by all *Europe* every Day. In the fame manner, after the Difcovery of the Circulation of the Blood, Thefes were maintained againft that Truth, and the Perfons who explained that new Difcovery, nick-named *Circulators,* by way of Ridicule.

Vain Objections againft thefe Difcoveries.

At length, there are fome who ftill hold out when obliged to yield to Evidence: they have feen the Fact, but they cavil at the Expreffion: they have declared War againft the Term Refrangibility, as well as againft thofe of Attraction and Gravitation.

But,

But, in the Name of Nonfenfe, what figni-
fies the Term, provided it implies a Truth?
When *Chriftopher Columbus* difcovered the
Ifland *Hifpaniola*, had he not a Right to call
it by whatever Name he thought fit? And
have not Inventors an equal Right to name
what they create or difcover? People have
cried out and wrote againft Words, which
Newton has ufed with the wifeft Precaution
to prevent Errors.

Criticifms
ftill more
abfurd.

He calls thefe Rays, red, yellow, &c.
rubrifick, flavifick Rays, that is to fay, ex-
citing the Senfation of red, yellow, &c.
His Intent in this was to ftop the Mouths of
thofe, who fhould have the Ignorance, or
Injuftice, to impute to him, that he believed
with *Ariftotle*, that Colours are in the things
themfelves, in the yellow and red Rays, and
not in our Mind. He had reafon to appre-
hend this Accufation. I have met with Per-
fons, and thofe too of fome Merit, who
have affured me, that *Newton* was a Peripa-
tetick, that he thought the Rays themfelves
actually coloured, as Fire was formerly be-
lieved hot; but the fame Criticks affured me
alfo, that *Newton* was an Atheift. It is true,

2   they

they had not read his Works, but they had heard them spoken of by others, who had wrote against his Experiments, without having seen them.

The gentlest Treatment those who wrote first against *Newton*, gave his System, was to say it was an Hypothesis; but what is an Hypothesis? A Supposition. And can Facts so often demonstrated be justly called a Supposition? Is it thro' Self-Love, that People will absolutely have the Honour of writing against a great Man? Ought they not rather to be better pleased with being his Disciples than Opponents? Is it because they are born in *France*, that they are ashamed of receiving Truth at the Hands of an *Englishman?* Such a Thought would ill become a Philosopher. Whoever thinks right, has no regard here to *French* or *English*; he that instructs us is our fellow Countryman.

H 4 CHAP.

CHAP. IX.

The Cauſe of Refrangibility ; from which it appears that there are indiviſible Bodies in Nature.

THE Refrangibility, which we have now ſeen, being united to Refraction, muſt have its Source in the ſame Principle. The ſame Cauſe muſt preſide in ſetting all theſe Springs in Motion : this is the Order of Nature. All Vegetables are nouriſhed by the ſame Laws ; all Animals have the ſame Principles of Life. Whatever happens to Bodies in Motion, the Laws of Motion are immutable. We have already ſeen, that the Reflection, Refraction, and Inflection of Light, are the Effects of a Power, which is not Impulſion (at leaſt known Impulſion :) this ſame Power ſhews itſelf in Refrangibility ; the Rays, which diſperſe themſelves to different Diſtances, inform us, that the Medium, in which they paſs, acts unequally upon them. A Group of Rays is attracted into the Glaſs ; but that Group is compoſed of Rays unequal

2   in

in their Substance. Those unequal Quantities therefore obey unequally the Power by which the Medium acts upon them. The more solid and compact a Ray of Light is, the more it must resist that Power, the less it must turn aside from its Course or Direction, and the less it must be refrangible. These Experiments confirm it in all Mediums and Cases. The red Ray is always that, which turns aside least from its Direction; and the violet, that which always turns aside most. So the red Ray has always more Substance, is harder, and more shining, and tires the Sight more. The violet, which of all the coloured Rays eases the Sight most, is the most refrangible, and consequently is composed of the finest, and least gravitating Parts. We must not believe here, that Light having Weight, and that one Ray weighs more than another, are meer Conjectures, formed at a venture.

Difference between the Rays of Light.

Experiments made by the most learned and judicious Persons, inform us, that many Bodies acquire Weight, after having imbibed Light for a considerable Length of Time. The Particles of Fire, which penetrate their

Light has Weight.

<div align="right">Substance,</div>

Subſtance, augment it.   But ſhould theſe
Experiments be called in queſtion; Fire is
Matter; therefore it has Weight, and Light
is nothing but Fire.

It is evident, that a white Ray * weighs all
the Rays that compoſe it.   Now ſuppoſe for
a Moment, that all the Rays of a Group e-
qually remove from one another, it is then
evident, that the red Ray being ſeven Times
leſs refrangible than the violet Ray, it ought
to have ſeven Times more Subſtance, and ſeven
Times more Weight, than the violet Ray.
Thus the red Ray weighing as ſeven ;   the
orange, we ſuppoſe here, as ſix ; the yel-
low, as five ; the green, as four; the blue,
as three ; the purple-indigo, as two; and
the violet, as one : the total Amount of all
theſe Weights being twenty-eight, and the
white Ray including them all, the white
Ray according to this Calculation, is demon-
ſtrated to weigh twenty-eight times as
much as the violet Ray †.

* By the white Ray is meant a Bundle of the ſeven dif-
rent Rays.

†'If the violet Ray be alſo a Bundle of as many Rays, it's
the fourth Part of the other.

We

We have already feen how prodigioufly fmall the Rays of Light muft be, which, containing in them all Colours from the Sun, penetrate a Pore of a Diamònd. Abundance of Rays enter that Pore, and unite near the interior Part of one of its Surfaces. Of this great number of Rays, that occupy fo fmall a Space, there is not any, that do not contain feven primordial Rays. Each of thofe Rays is itfelf a Group of Rays tinged with its Colour. The red Ray is an Affemblage of a very great Number of red Rays. The violet is an Affemblage of violet Rays. If therefore this Group of violet Rays weighs eight and twenty times lefs than one of white Rays *, what muft a fingle one of them weigh ?

Here he differs from p. 102 at the bottom

Let us confider one of thefe fingle Rays, that differs from one of another Colour; for Inftance, the fmalleft of the red Rays differs in every thing from the fmalleft of the violet : The folid Parts of which it is compofed, muft be fo many Atoms perfectly hard. And indeed, if Bodies were not compofed of

Atoms of which Light is compofed.

---

* Not the Group but one Ray in it, for the Rays in the one are as many as in the other.

folid, hard, indivifible Parts, that is to fay, of real Atoms, how could the Species of Bodies continue eternally the fame? How could fo invariable a Difference be preferved? Muft not the Parts, that conftitute their Effence, be fufficiently hard, folid, and firm, to be al-

Atoms are the Principles of Bodies.

ways what they are? For how in the Texture of a fingle Grain of Corn, would fo many Grains of Corn be included, and nothing elfe, if the Configuration of its fmall Parts were not always the fame, and always folid and indivifible : which implies nothing elfe but always undivided ? In the Egg of a Fly there are Flies *ad infinitum* ; but if thofe fmall Parts, which contain fo many Flies, were not perfectly hard, they would certainly be broke in pieces againft each other, thro' the rapid Motion in which every thing in Nature is. They would be broke fo much the more, becaufe the fmaller Bodies are, the more Surface they have in Proportion. However this Inconvenience does not happen : the Egg of a Fly always produces the Flies it contained ; every Seed, from that of Gold to that of Muftard, remains eternally the fame. It is therefore to be believed, that all the

Seeds

Seeds of things are compofed of Atoms always undivided, of which the Subftances of every Thing confift; but it is not fufficient to point out this great Truth, to which the Obfervation of the Rays of Light has led us; we muft demonftrate it, and prove in the ftricteft Manner, that Atoms phyfically indivifible neceffarily exift *; which is what we proceed to fhew in the following Chapter.

* He means not Atoms that have no Parts, but that the Parts are not feparable, as pag. 111. line 12.

C H A P.

CHAP. X.

Proofs that there are indivisible Atoms, and that the simple Particles of Light are Atoms of that kind. Discoveries continued.

WE have already seen how extremely porous all Bodies are. Water itself, which is but nineteen times less heavy than Gold, passes however thro' its Pores, tho' the most solid of Metals. There is no Body, which has not incomparably more Pores than Matter: but let us suppose a Cube, if you please, which has as much apparent Matter as it has Pores: by this Supposition then it will actually have only half the Matter it appears to have * ; but each Part of this Body being in the same Case, and losing in like manner the half of itself, this Cube then, by this second Operation, will be only the fourth Part of itself; in Consequence it will have only the fourth Part of the Matter it seems to have. Dividing in this manner each Part of each Part, the eighth Part of the

Proof of the Existence of Atoms.

* If the Matter be actually one half and the Pores the other half, the Matter hath no Pores, and there is an End of it.

Matter

Matter will remain.   This Progreffion continued *ad infinitum*, and the Divifion carried on thro' all Degrees of Infinite, the End of the encreafing of the Pores will be Infinity, and the End of the Diminution of Matter will be nothing.   Therefore if Matter could be phyfically divided *ad infinitum*, it would be found, that there would be nothing but Pores and no Matter.   Matter then, fuch as it is, is not in reality phyfically divifible *ad infinitum :* Therefore it is evident, that there are indivifible Atoms, that is to fay, Atoms which will never be divided, as long as the prefent Conftitution of the World fubfifts.

Let us confider this Demonftration in a ftill more palpable manner.   I am come by my Divifion to the two laft Pores :   there either is a Body between them, or there is not, if there is not, there was then no Matter ;   if there is, that Body is then without Pores.   I fay it is without Pores ;   becaufe I am come to the laft Pores, this Particle of Matter is therefore actually indivifible.

Moreover, this Propofition ought not to appear contradictory to Geometrical Demonftration, which proves a Line divifible to Infinity.   Thefe

This is either unintelligible or falfe.

*The Divifi-
bility of
Matter
does not
prevent the
Exiftence
of Atoms.*

Thefe two Propofitions, which feem to deftroy each other, agree very well together. Geometry has for its Object the Ideas of the Mind. A Geometrical Line is a Line in Idea, always divifible in Idea, as a numerical Unity is always reducible into as many Unites as I think fit to conceive. I can divide the Unity of a Foot into an hundred thoufand millions of millions of other Unites; but then I can always confider the fame Foot as a fingle * Unity.

Points without Lines, Lines without Superficies, Superficies without Solids, the Infinite 1, the Infinite 2, the Infinite 3, are in reality the Objects of certain Geometrical Propofitions: but it is no lefs certain that Nature cannot produce Superficies, Lines, or Points, without Solids. It is no lefs indifputable, that a Line in Geometry is divifible to Infinity; it is alfo certain, that there are

* Mr. *de Malefieu*, in the Duke of *Burgundy*'s Geometry, has not fufficiently confidered this Truth, p. 117. He finds Contradiction where there is none. He asks as a Queftion not to be folved, whether a Foot of Matter be one Subftance, or many? It is certainly one Subftance, when confidered as a Cubick Foot. But it is feventeen hundred and twenty-eight Subftances, when divided into Inches.

indivifible

indivifible Bodies in Nature, that is to fay, undivided Bodies, Bodies which will remain fuch, as long as the prefent Conftitution of Things fubfifts.

Let us hold therefore as certain, that there are Atoms. Each conftituent Part of a fimple coloured Ray, may be confidered as an Atom; each of thefe Atoms is of Weight; it is the different Attraction, which caufes the different Refraction. Let us conceive, that the moft refrangible of thefe Atoms are alfo the moft reflexible, and that as they are refracted in Proportion to their Attraction towards the moft actuating Medium, it follows, that they are reflected in Proportion to the fame Attraction. It is eafy to know at this time, that the violet Ray, for Inftance, which is the moft refrangible, is always the firft reflected on quitting the Prifm which has received all the Rays. *Newton* made this Experiment by the help of four Prifms, with a Sagacity and Induftry worthy of the Difcoverer of fo many Truths,

I fhall here give the moft fimple of his Experiments.

The Prism has thrown the seven Colours upon the Paper: turn the Prism upon itself in the manner A, B, C, and you will presently have the Angle, according to which all Light will be reflected from the inside to the outside of the Prism, instead of being thrown upon the Paper: as soon as you begin to approach that Angle, you see on a sudden the violet Ray quit the Paper, and rise to the Cieling.   After the violet, the purple does the same, after the purple the blue; and so on, till the red quits its place upon the Paper last, and is reflected on the Cieling in its turn. Every Ray therefore is the more reflexible in proportion as it is more refrangible: in Consequence the same Cause produces Reflection and Refraction.

Now the solid Part of the Glass occasions neither this Refraction, nor this Reflection: once more then these Properties have their Rise in some other Cause than the Impulsion, known to us upon the Earth.   There is nothing to be said against these Experiments; we must submit to them however tenacious we are against Evidence.

Matter

Matter might be taken even from *Newton*'s Experiments to form some Difficulties against the Laws he establishes. One might tell him, for Instance: you have proved that no known Impulsion of Body can produce either the Refraction or Reflection of Light, because it is refracted in Pores, and reflected in Void: you have told us, that there is a Power in Nature which makes all Bodies tend towards each other; and till you shew us, as you have promised, the Laws by which that Power acts, we conceive, that it must act in Effect upon all Matter, and that the smallest Bodies imaginable must be determined in the same manner by this Power, as the greatest Bodies possible: you have told us, that one of the Laws of this Power is to act upon all Bodies according to their Quantity or Substance; and we confess that to be very probable; but do not your own Experiments contradict this System? Water has much more Solidity or Substance than Spirits of Wine, or Spirits of Turpentine; it however attracts the Rays of Light less; those Rays are not so much refracted in Water as in Spirits of Wine; this Power of Gravitation and Attraction

there-

therefore does not act, as you tell us, according to Quantity or Substance.

This Objection, far from making the Truth of the new Discoveries doubtful, really confirms it. To answer it clearly let us consider, that all Bodies tend towards the Center of the Earth; that they all fall in the Air with a Force proportioned to their Mass or Substance; but if besides this Force another be applied to them, they will move with greater Velocity than they have from their own Weight. This is the Case of the Rays of Light when they enter Bodies already full of fiery Particles, which are nothing but Light itself retained in their Pores.

These Atoms of Fire, which actually reside in certain sulphurous and transparent Bodies, encrease the Refraction of Light towards a perpendicular Line, as a new Force applied to it: it happens in this Case, as in that of a Torch just put out and still smoaking; it will light again at a certain distance from another lighted Torch.

It is entirely as natural for the Rays of Light to enter with Ease into the sulphurous Spirit of Turpentine, as for the Flame to

catch

catch the smoaking extinguished Torch;
now a new Cause added to Refraction neces-
sarily augments it.

Besides which Re-action is always equal to
Action : Sulphurous Bodies are those on
which Fire, that is nothing but Light, acts
with greatest Force; those Bodies therefore
must also act upon, break and refract Light
more than any other.

Let us here observe, that this Attraction *Attraction*
inherent in Matter, does not extend univer- *does not*
extend to
sally, and produce all Effects. The Mystery *all the Ef-*
of Light reflected from the midst of Pores, *fects of*
Light.
and from above Surfaces without touching
them, has Depths which the Laws of At-
traction cannot fathom : only Quacks boast
of Universal Medicines; and he would be a
Quack in Philosophy, who should refer every
thing without Proof to the same Course:
the same Force of Mind, which enabled
Newton to discover the Power of Attraction,
made him confess that that Power was far
from being the sole Agent of Nature.

It is true, that the most refrangible Ray
being the most reflexible, is an evident Proof,
that the same Power operates the Reflection,

Refrac-

Refraction, and Acceleration of the Rays in the Glaſs, &c. but however, the Force of Attraction ſeems to have nothing in common with other Phænomena. There are eſpecially Vibrations of Rays, alternative Dartings of Light, backwards and forwards over Bodies, which could not be explained by Gravitation; but theſe new Difficulties *Newton* himſelf did make. He has not only diſcovered the Myſteries, which Gravitation reveals, but others, which it does not reveal. Theſe alternative Dartings of the Reflection of Light, are one of the Secrets of Nature, which, it is aſtoniſhing, human Eyes have ever been able to perceive.

We ſhall ſpeak of this Singularity in its Place in the thirteenth Chapter; let us continue our view of the Effects of Refrangibility. The Rainbow is one, and the moſt conſiderable of its Effects, which we proceed to explain in the following Chapter.

CHAP. XI.

*Of the Rainbow; that Phænomenon a ne-
cessary Effect of the Laws of Re-
frangibility.*

THE Rainbow, or Iris, is a necessary
Effect of the Properties of Light, of
which we have just been speaking. There is
nothing in the Writings of the *Greeks, Romans,*
or *Arabians,* that gives us reason to believe,
they knew the cause of this Phænomenon.
Lucretius says nothing of it, and by all the
Absurdities, which he vents in the Name of
Epicurus upon Light and Vision, it appears,
that his Age, so polite in other Respects, was
profoundly ignorant in Point of Physicks.
They knew, that to see what we call the
Rainbow, or Iris, a thick Cloud is necessary,
dissolving in Rain before the Rays of the Sun;
and that our Eyes should be between that
Star and the Cloud, *Mille trahit varios ad-
verso sole Colores,* but this was all they knew;
no-body imagined either why a Cloud exhi-
bited Colours, how the Nature and Order of

*Mecha-
nism of the
Rainbow
entirely
unknown
to the An-
cients.*

I 4   those

those Colours are determined, or wherefore we always fee that Phænomenon under the Form of a Semi-circle.

Albertus, furnamed *Magnus the Great*, becaufe he lived in an Age wherein Men were very little, imagined that the Colours of the Rainbow proceeded from a Dew between us and the Cloud, and that thofe Colours received upon the Cloud, were tranfmitted by it to us. You will obferve befides, that this *Albertus Magnus* believed, with all the Schools, that Light was an Accident.

The Archbifhop Antonio de Dominis was the firft, who explained the Rainbow.

At length the celebrated *Antonio de Dominis*, Archbifhop of *Spalatro* in *Dalmatia*, expelled from his Bifhoprick by the Inquifition, about the Year 1590, wrote his little Treatife, *De Radiis Lucis & de Iride*, which was not printed at *Venice* till twenty Years after. He was the firft who fhewed, that the Rays of the Sun, reflected even from the inner Part of Drops of Rain, formed thofe Colours, that appeared in the Bow, which feemed an inexplicable Miracle; he rendered the Miracle Natural, or rather he explained it by new Prodigies of Nature.

His

His Difcovery was fo much the more fingular, as in other Refpects he had very falfe Notions of the manner in which Vifion is performed. He affures us in his Book, that the Images of Objects are in the Ball of the Eye, and that there is no Refraction in it : a Notion fingular enough for a good Philofopher! He had difcovered Refractions, unknown before, in the Drops of the Rainbow, and denied thofe operated in the Humours of the Eye, of which himfelf began the Demonftration ; but let us leave his Errors to examine the Truth he difcovered.

He faw with a Sagacity very uncommon in thofe Days, that every Row or Circle of Drops of Rain, that form the Rainbow, muft tranfmit the Rays of Light in different Angles, he alfo faw, that the difference of thofe Angles muft occafion that of the Colours : he *His Experiment.* found means to meafure the Magnitude of thofe Angles : he took a very tranfparent Cryftal Ball which he filled with Water, and hung up at a certain Height expofed to the Rays of the Sun.

Defcartes, who followed *Antonio de Domi-* *Imitated by Defcartes.* *nis*, and rectified and furpaffed him in fome things,

4

things, and who perhaps ought to have quoted him, made alſo the ſame Experiment. When this Ball is ſuſpended at ſuch an Height, that the Ray of Light, which falls from the Sun upon the Ball, makes an Angle with the Ray, that falls from the Ball to the Eye, of forty two Degrees two or three Minutes, the Ball always exhibits a red Colour.
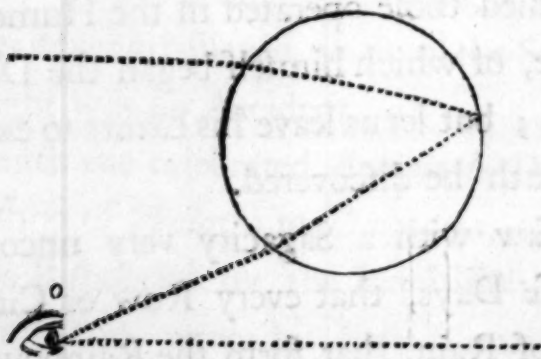
When that Ball is ſuſpended a little lower, and thoſe Angles are ſmaller, the other Colours of the Rainbow appear ſucceſſively in ſuch a manner, that the greateſt Angle in this Caſe forms the red, and the ſmalleſt of forty Degrees ſeventeen Minutes forms the violet. This is the Foundation of the Knowledge of the Rainbow; but at the ſame time it is only the Foundation of it.

Refran-

Refrangibility alone explains a Phænome- non fo common, fo little known, and of which few Beginners have a clear Idea: let us endeavour to render the thing obvious to all the World. Let us fufpend a Ball of Cryftal full of Water, expofed to the Sun: let us place ourfelves between the Sun and it; wherefore does this Ball tranfmit Colours to me, and wherefore particular Colours? Great quantities of Light, millions of Groups of Rays, fall from the Sun upon this Ball: in each of thofe Groups there are primitive Rays, homogeneous Rays, many red, many yellow, many green, &c. all which break at their Incidence into the Ball, each differently and according to its Species, and the Place in which it enters.

You already know that the red Rays are the leaft refrangible; the red Rays of a certain determinate Group will therefore unite at a certain determinate Point at the bottom of the Ball, whilft the blue and purple Rays of the fame Group will do the fame elfewhere. Thefe red Rays will alfo quit the Ball at one place, and the green, blue, and purple at another. This is not enough. We

muft

muſt examine the Points, where thoſe red Rays fall in entring the Ball, and in quitting it to come to the Eye.

To make this as clear as poſſible, let us conceive this Ball, as it really is, an Aſſemblage of an infinite Number of plane Superficies; for the Circle being compoſed of Right-points infinitely ſmall, the Ball is only an Infinity of ſuch Superficies.
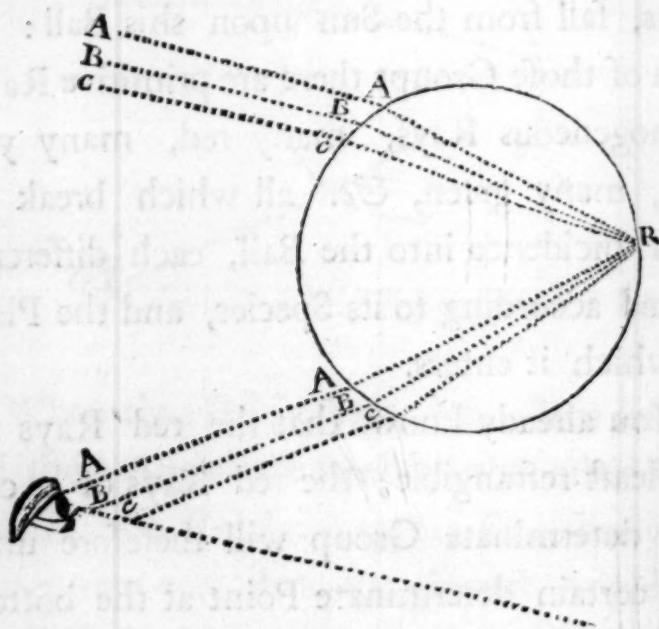
The red Rays A, B, C, fall parallel from the Sun upon thoſe three ſmall Superficies. Is it not true that each of them breaks according to its Degree of Incidence? Is it not
mani-

manifeſt that the red Ray A, falls more ob-
liquely upon its little Superficies, than the
red Ray B doth ? Thus both come to the
Point R, by different Ways or Directions.

The red Ray C, falling upon its little Su-
perficies ſtill leſs obliquely than the two for-
mer, is much leſs broke, and arrives alſo at
the Point R, with very little Incurvation.

I have now three red Rays, that is to ſay, *That Phæ-*
three Groups of red Rays, which terminate *nomenon*
at the ſame Point R.   *explained.*

At this Point R, each of them makes an
Angle of Reflection equal to its Angle of
Incidence, each is broke at emerging from
the Ball in a Line removing from the Per-
pendicular of the new little Superficies it comes
to, in the ſame manner as each is broke at
its Incidence in Lines, approaching each o-
ther, to their Perpendiculars ; all therefore re-
turn parallel, and enter the Eye according
to the opening of the Angle peculiar to the
red Rays.

If there be a ſufficient quantity of theſe
homogeneous red Rays to move the optick
Nerve, we muſt indiſputably have the ſen-
ſation of red.

Theſe

These Rays A, B, C, are termed the visible and operative Rays of the Drop of Rain; for each Drop has its visible Rays.

There are thousands of other red Rays, which falling upon other little Superficies of the Ball, higher and lower, or which falling on the same Superficies at another Obliquity, do not terminate in R; these are lost to you, but will be seen by other Eyes placed higher or lower.

Abundance of orange, green, blue and violet Rays have fallen indeed with the visible red ones upon the Superficies A, B, C; but you cannot receive them. You know the reason, which is their being all more refrangible than the red Rays: it is because in entering all at the same Point, each of them takes a different Path in the Ball; as they are all more broken, they come below the Point R, and break also more than the red ones in quitting the Ball. The same Power, which in the inside of the Ball made them approach in a Line more remote from the Perpendicular of each Superficies, disperses them therefore more at their return into the Air: they all return therefore above the Eye; but lower

the

the Ball, and the Angle becomes lefs. Let this Angle be of forty Degrees and about feventeen Minutes, and you will fee no Colour but the violet.

There is no-body who upon this Principle may not eafily conceive the Doctrine of the Rainbow; imagine feveral Rows or Circles of Drops of Rain; every Drop has the fame Effect as this Ball.

Caft your Eye upon the Bow R, V, P, and to avoid Confufion, confider only three Rows of Rain-drops, three coloured Circles.
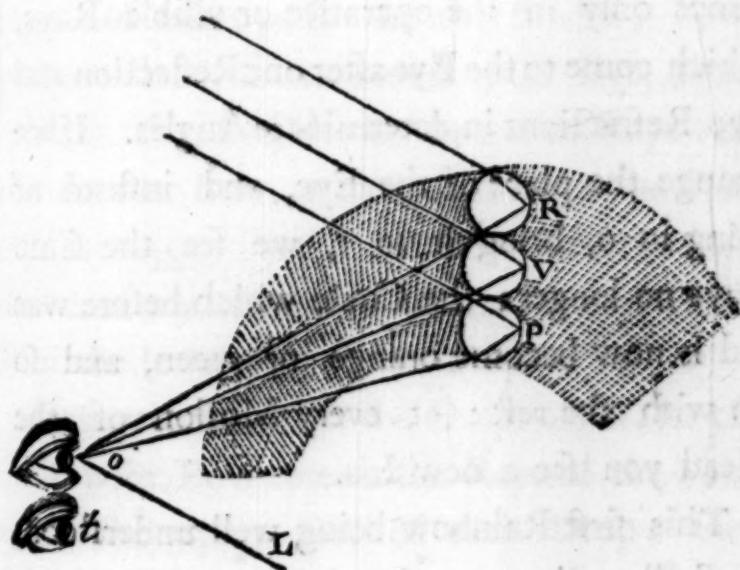
It is vifible that the Angle P, o, L, is lefs

than

than the Angle V, o, L, and that the Angle R, o, L, is the greateſt of the three. The greateſt Angle of the three is therefore that of the red primordial Rays: that in the middle is that of the primitive green; and the leaſt P, o, L, is that of the primitive purple. We therefore muſt ſee the Rainbow red on its external, green on its middle, and purple and violet on its internal Circles. Obſerve only, that the laſt Circle, the violet, is always tinged with the whitiſh Colour of the Cloud in which it loſes itſelf.

It is eaſy to conceive then, that we ſee the Drops only in the operative or viſible Rays, which come to the Eye after one Reflection and two Refractions in determinate Angles. If we change the place of the Eye, and inſtead of being in o, bring it to t, we ſee the ſame Rays no longer: the Circle which before was red is now become orange or green, and ſo on with the reſt: at every Motion of the Head you ſee a new Iris.

This firſt Rainbow being well underſtood, we ſhall eaſily comprehend the ſecond, which is generally ſeen encircling the firſt, and which is called the falſe Rainbow, or *faint Bow*,

be-

becaufe its Colours are not fo lively, and are reverfed in their order to thofe of the other.

For the Appearance of two Rainbows, it *Two Rain-* fuffices that the Cloud which forms them be *bows.* fufficiently thick and extended. That Bow which appears above the firft and furrounds it, is formed in like manner by the Rays, which the Sun darts into the Rain-drops, and which are broken and reflected in them in fuch a manner, that each Row of Drops tranfmits alfo primitive Rays to the Eye; this Drop a red, and that a violet Ray.

But every thing in this great Bow is the reverfe of what paffes in the fmaller; how comes that ? It is becaufe your Eye, that receives the fenfible or operative Rays of the fmaller Bow, which fall from the Sun into the upper Part of the Drops, receives on the contrary the Rays of the greater Bow from the lower part of the Drops.

You perceive, that the Drops of Water of the fmaller Bow receive the Rays of the Sun upon the upper part of each Drop; the Drops of the greater Bow on the contrary receive the Rays, that reach them, on their lower part. Nothing in my Opinion will be

K   more
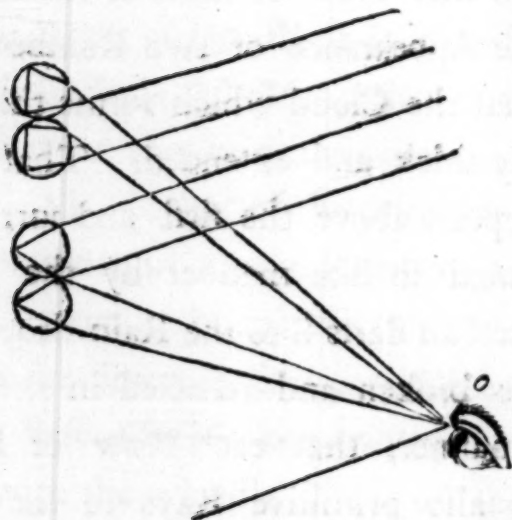
more eaſy to conceive, than the manner in
which the Rays are twice reflected in the
Drops of the great Rainbow, and how thoſe
Rays twice refracted and twice reflected ex-
hibit an Iris reverſed in the order of its Co-
lours, and fainter than the former.   You
have juſt ſeen that the Rays enter thus into
the little lower Part of the Drops of Water
of this exteriour Iris.

A number of Rays fall on the Superficies
of the Drop in G, a part of thoſe Rays are
refracted there within, and another ſcattered
without ; thus the Eye has already loſt part
of thoſe Rays. The Part refracted comes to

                                                        H,
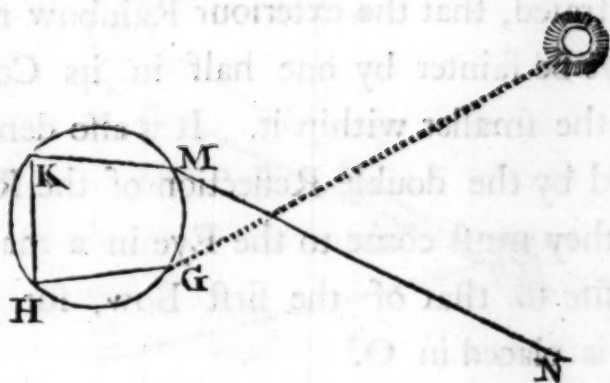
H, one half of this Part is difperfed in the
Air on quitting the Drop, and is again loft
to the Eye. The little that remains in the
Drop is tranfmitted to K, there a Part of it
efcapes again: this is a third Diminution.
What has remained of it in K is transferred
to M, and on this Emergence to M, a Part
of it is again diffipated: fourth Diminution ;
and what remains comes to the Eye at laft in
the Line M, N. Thus therefore we fee in
this Drop as many Refractions as in the
Drops of the fmaller Bow; but there are, as
we have fhewn, two Reflections inftead of
one in this greater Bow. Twice the Light
therefore is loft in the greater Bow, in which
the Light is twice reflected, whilft lefs by one
half is loft in the fmaller Bow, where the

Drops are once reflected. It is therefore demonstrated, that the exterior Rainbow must always be fainter by one half in its Colour than the smaller within it. It is also demonstrated by the double Reflection of the Rays, that they must come to the Eye in a manner opposite to that of the first Bow, for your Eye is placed in O.

In this place O, it receives the least refrangible Rays of the first exteriour Circle of the smaller Bow, and must receive the most refrangible of the first Circle of the second greater Bow; these most refrangible Rays are the violet. Thus then we have here the two Rainbows in their natural Order, giving them only three Colours to avoid Confusion.

This Phæ-
nomenon
always
seen in a
Semi-cir-
cular Fi-
gure.

It only remains for us to know wherefore those Colours are always perceived in a circular Figure. Consider this Line O, Z, which passes thro' your Eye. Conceive the two Balls R, V, to move always at equal Distances from your Eye; they will describe the Bases of Cones, of which the Points will always be in your Eye.

Con-
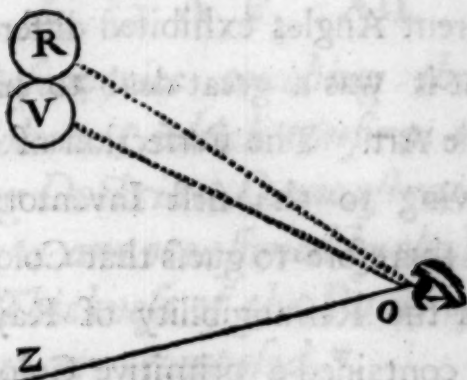
Conceive that the Ray of the Drop of Water R, coming to your Eye o, turns round this Line o, Z, as round an Axis, making always an Angle with your Eye of forty-two Degrees two Minutes; it is plain this Drop will defcribe a Circle, which will appear red. Suppofe the other Drop V, to turn in the fame manner, making always another Angle of forty Degrees feventeen Minutes, it will form violet Circle; all the Drops therefore in this Plan will form a violet Circle, as thofe in the Plan of the Drop R, will a red one. We fee therefore this Iris as a Circle, but not as an entire Circle; becaufe the Earth cuts it, we fee only an Arch, the Section of a Circle.

Neither *Antonio de Dominis* nor *Defcartes* could penetrate any farther into moft of thefe

K 3 Truths:

Truths: they could not difcern wherefore thefe different Angles exhibited different Colours; but it was a great deal to have difcovered the Art. The Perfection of Arts are feldom owing to the firft Inventors. Not being able therefore to guefs that Colours depended on the Refrangibility of Rays, that each Ray contained a primitive Colour in itfelf, that the different Attraction of thofe Rays was the caufe of their different Refrangibility, and occafioned thofe Removals which formed the different Angles, *Defcartes* abandoned himfelf to his Spirit of Invention to explain the Colours of the Rainbow. In order to this he employed the imaginary *whirling round of Globules* and his *Tendency to whirling round*; Proofs of Genius, but Proofs of Error. Thus to explain the *Syftole* and *Diaftole* of the Heart, he imagined a Motion and Conformation of that Organ, of which all Anatomifts have admitted the Falfity. *Defcartes* would have been the greateft Philofopher of the World, if he had invented lefs.

CHAP. XII.

New Discoveries touching the Cause of Colours, which confirm the preceding Doctrine, Demonstration that Colours are occasioned by the Density and Thickness of the Parts of which Bodies are composed *.

IT refults then, from what has hitherto been faid, that all Colours proceed from the Mixture of the feven primitive ones, of which the Rainbow and the Prifm give us a diftinct View.

The Bodies that are moft proper to reflect the red Rays, and whofe Parts either abforb or tranfmit the other Rays, will be red; and in like manner of the reft. The Meaning of this is not, that the red Rays are actually reflected by the Parts of thefe Bodies; but that there is a Power, a Force hitherto unknown, which reflects thefe Rays from about the Surfaces of Bodies, and the Cavity of their Pores.

Colours then are in the Rays of the Sun,

* Or as in pag. 137, line 2, the Thicknefs of the Parts that compofe the Surfaces only, and pag. 138, line 15, and pag. 140, line 13.

K 4 and

and return to us from the Surfaces and Pores of Bodies, and from the Vacuum. Let us now enquire in what the apparent Power of Bodies to reflect thefe Colours confifts, what occafions Scarlet to appear red, why the Meadows are green, and why a clear Heaven is blue: For to fay that this proceeds from the Difference of the Form of their Parts, is to advance an indeterminate Notion, that makes us never the wifer.

A childifh Diverfion, that feems to have nothing in it but what is contemptible, gave Sir *Ifaac Newton* the firft Idea of thefe recent Truths which we are now to explain. Every Thing to a Philofopher may be a Subject of Meditation, and nothing is defpicable in his Eyes. He perceived, that in thofe Bubbles

of Soap and Water that are blown up by Children, the Colours changed every Moment, paffing downwards fucceffively from the Top of the Bubble, in proportion as the Thicknefs of it diminifhed, till at laft the Weight of the Water and Soap, which ftill fall to the Bottom, breaks the Equilibre of that light Sphere, and caufes it to vanifh. He prefumed from hence, that Colours

might

might probably depend on the Thickness of the Parts that compofed the Surfaces of Bodies ; and to affure himfelf of it, he had recourfe to the following Experiments *.

Let two Glaffes touch one another in a fingle Point. They need not be both convex ; it is fufficient that the firft is fo, and that it be placed upon the other in this manner.

An Experiment of Sir Ifaac.

Let Water be put between thefe two Glaffes, to render more fenfible the Experiment which is made at the fame Time in the Air. When the Glaffes are preffed a little againft each other, a fmall, tranfparent, black Spot appears at the Point of their Contact. From this Point, furrounded with a little Water, coloured Circles form themfelves, in the fame Order and Manner as in the Bubble of diluted Soap. In a Word, by meafuring the Diameter of thefe Circles, and the Convexity of the Glafs, Sir *Ifaac Newton* determined the different Thicknefs of the

* There feems to be a difference between the Parts of Gold or Scarlet Cloth, and Bubbles of Water that are hollow and tranfparent.

Por-

Portions of Water which gave thefe diffe-
rent Colours. In particular, to reflect white
Rays, he found that the Thicknefs requifite,
was about the 250,000ᵗʰ Part of an Inch,
that is, about four fuch Parts of an Inch as
the Divifion of it into a Million would pro-
duce. The azure Blue, and the Colours bor-
dering upon a Violet, depend on a Thick-
nefs yet much lefs. Thus the pureft Va-
pours which arife from the Earth, and which
colour the Air without clouding it, being of
a very thin Surface, produce that celeftial
Blue which charms our Sight.

This Difcovery, that Colours are attached
to the Thicknefs of Surfaces, has been fup-
ported by other Experiments, no lefs curious
than what we have now mentioned.

The fame Body that was green, when it
was fomewhat thick, has become blue, when
it has been rendered thin enough to reflect
nothing but blue Rays, and to tranfmit all
the others. Thefe Truths, of fo delicate a
Refearch, and which feem to withdraw
themfelves from human Sight, deferve well to
be clofely purfued: This Part of Philofophy
is by a Microfcope, with which the Mind dif-
covers Magnitudes infinitely fmall *. All

* But not the Atoms in the Rays of Light.   4

Colours de-
pend on the
Thicknefs of
the Parts
of Bodies,
notwith-
ftanding
that thefe
Parts re-
flect not the
Light
themfelves.

All Bodies are transparent; we have only to reduce them to a proper Tenuity, and then the Rays of Light, finding but a thin Plate, but a Leaf to pass thro', make their Passage accordingly. Thus when a Leaf of Gold is placed against a single Hole in a dark Room, it reflects from its Surface the yellow Rays, which cannot pass thro' its Substance, and transmits green Rays into the Room; so that Gold then produces a green Colour. This is a farther Confirmation of what was before advanced, that Colours depend on the Difference of Densities.

A yet stronger Proof of the same thing, is in the Experiment of the two Glasses, which are made to touch in a convex Point: The Water here is not the only Element that produces different Colours according to its different Densities; the Air produces the same Effect, only the coloured Circles that it makes between the two Glasses, have a larger Diameter than those of the Water.

There is a secret Proportion therefore, established by Nature, between the Force of the constituent Parts of all Bodies, and the primitive Rays which colour those Bodies: The

thinnest

thinneſt Bodies give the moſt feeble Colours, and to reflect a Black, the ſame Thickneſs, or rather the ſame Tenuity, the ſame Thinneſs is requiſite, as that which conſtitutes the very Top of a Bubble of diluted Soap, in which a little black Spot is perceived; or even the ſame as is in the Point of Contact between the convex and the flat Glaſs, which Contact produces alſo a black Spot.

And that nevertheleſs, the ſolid Parts do not reflect the Light.

But once more; It muſt not be imagined that Bodies reflect the Light by their ſolid Parts, becauſe we have ſhewn that Colours depend on the Denſity of theſe Parts: There is a Power attached to that Denſity, a Power that acts near the Surface; yet it is not in the leaſt the ſolid Surface, that repells, that reflects. This Truth ſhall be more ſenſibly demonſtrated in the following Chapter, than it has hitherto been. It ſeems to me, that the Reader ſhould by this Time be arrived at a Point, where nothing ought to ſurpriſe him for the future: But what he has juſt been ſeeing will lead him farther than he may imagine; ſo many Singularities being, if we may uſe the Expreſſion, but the Frontiers of a new World. 4

C H A P.

CHAP. XIII.

Consequences of these Discoveries. The mutual Action of Bodies upon Light.

THE Reflection of Light, its Inflection, its Refraction, its Refrangibility being known, the Origin of Colours being discovered, and even the necessary Thickness of Bodies to occasion certain Colours being determined ; it remains that we should examine two more Properties of Light, not less new, nor less surprising than the rest. The first of these Properties is that Power itself which acts near the Surfaces of Bodies, and which is a mutual Action of the Light upon Bodies, and of Bodies upon the Light. The second is a Resemblance which is found between Colours and the Notes in Musick, between the Objects of the Sight and those of the Hearing. We proceed to render an Account of these two miraculous Qualities : and with this Account we shall finish our Introduction to Sir *Isaac Newton*'s Opticks.

<div align="right">You</div>

You have seen that two Glasses, touching one another in a Point, produce Circles or Rings of different Colours, as red, blue, green, white, &c. Make the Trial of these Glasses in your dark Room, where you made the Experiment of the Prism exposed to the Light that comes in on it through a Hole. You remember, that in this Experiment of the Prism you saw the Decomposition of Light, and the Anatomy of its Rays: You placed a Sheet of white Paper over against the Prism, which Paper received the seven primitive Colours, every one in its proper Order. Now expose your two Glasses to one of the coloured Rays, which you please, as reflected from the Paper; you shall always see that coloured Circles will form themselves between these Glasses, but that these Circles will then be of the Colour of the Rays which are reflected to you from the Paper. Hold up your Glasses, for Instance, to the Light of the red Rays, and you shall have red Circles only between them: But, what is very surprizing, between every one of these red Circles there will be a Circle quite black. To clear up this Matter, and the

A very singular Experiment.

the Singularities that are attached to it, yet more perfectly, take your Glasses from the Paper, and present them to the Prism itself, in such a manner as that one of the Rays which escape from the Prism, a red one for Example, may fall upon the Glasses; still red Circles only will form themselves between the black ones: then put the Sheet of Paper behind your Glasses, and every black Ring will produce a red one on the Paper, and every one that is red when reflected towards you, will produce a black one on the Paper.

It results from this Experiment, that the Air or the Water which is between your Glasses, reflects the Light in one Place, and in another lets it pass, or transmits it. I confess, I cannot here sufficiently admire that Depth of Penetration, that Sagacity more than Human, with which Sir *Isaac* has pursued these imperceptible Truths; he was satisfied of those wonderful Propositions, even by Measure and Calculation.

At the Point of Contact of the two Glasses, you see no Reflection of any Light: immediately after this Contact, the first and thinnest Body of Water or Air, that touches the black
Point,

Point, produces a Reflection: the Water or Air of a second Degree of Denfity, that is, twice as thick as the firſt, reflects nothing: that of the third, which has thrice the Denfity of the firſt, reflects: that of the fourth Degree, like the fecond, does not reflect: that which has five Times the firſt Thickneſs, tranſmits: that which has fix, tranſmits nothing. So that the black Circles follow in this Progreſſion, 0, 2, 4, 6, 8, and the coloured and luminous ones in this, 1, 3, 5, 7, 9.

Confequences of theſe Experiments. What paſſes in this Experiment, happens in like manner in other Bodies, which all reflect one Part of the Light, and receive another Part of it into their Subſtances. This Property then is fully demonſtrable to the Mind, and even to the Sight, that it is not the ſolid Surface which reflects the Light. For, in ſhort, if ſolid Surfaces did really reflect; 1ſt, The Point of Contact, in the two Glaſſes would have this Quality, and not be obfcure, as we ſee it. 2dly, Every ſolid Part, which gave you only one ſort of Rays, ought alfo to have given you every Species of them. 3dly, The ſolid Parts would not tranſmit the
Light

Light in one Part, and reflect it in another; for being all solid, they would all reflect. 4thly, If Light was reflected by solid Parts, it would be impossible to see one's self in a Looking-glass, as we have before said; because the Glass being rugged and uneven, could not send back the Light in a regular manner *. It is indubitable then, that there is a Power acting about Bodies, without touching them, and that this Power acts between these Bodies and the Light. In a Word, far from striking on the Bodies themselves, and rebounding back to us, we have reason to believe that the greatest Part of the Rays of Light which impinge against solid Parts, remain there, are there lost, are there extinguished.

This Power, which acts about Surfaces, acts from one Surface to another. It is chiefly from the last Surface, on the farther side of a transparent Body, that the Rays rebound: We have proved this before.

* And yet it does, because smoother than other Surfaces, though many Rays are lost by some Degrees of Ruggedness; but if there be no Contact, no matter whether rugged or smooth, the Power of reflecting might reside with the one as well as the other.

We

We muſt admit a Power then, which acts upon the Rays of Light from above one of theſe Surfaces to the other, a Power which tranſmits and reflects the Rays alternately. This Play between Light and Bodies was not merely ſuſpected by Sir *Iſaac Newton*; he has computed many thouſands of theſe alternative Vibrations, theſe tranſmitted and reflected Throws. But, this Action of Bodies upon Light, and of Light upon Bodies, leaves us yet many Uncertainties in the manner of explaining it.

He who diſcovered this Myſtery, was not able, in the Courſe of his long Life, to make Experiments enough to aſſign the certain Cauſe of theſe Effects. But even tho' by his Diſcoveries he had taught us only new Properties of Matter, would not this alone have been a ſufficient Service rendered to Philoſophy? He conjectured that Light flows

from the Sun, and other luminous Bodies, by Starts, by Vibrations; that the firſt of theſe Vibrations operates a Reflection, the ſecond a Tranſmiſſion, and ſo on to Infinity. He had alſo prepared Experiments, which might conduce to ſhew us wherein this Sport of

Nature

Nature agrees with the Grand Principle of Attraction: but he had not Time to finish his Researches. He conjectured moreover, that there is in Nature a very elastic and thin Matter, which becomes by so much the more thin, as it is farther distant from opaque Bodies; that the Starts or Throws of Light excite Vibrations in this elastic Matter: And it must be confessed, that this Hypothesis accounts for almost all the Mysteries concerning Light, and above all for the Attraction and Gravitation of Bodies. But an Hypothesis, even tho' it gives a Reason for almost every thing, ought not to be admitted. It is not sufficient that a System be possible to make it be believed; it ought to be proved. If the Vortices of *Descartes* could support themselves against all the Difficulties with which they are embarrassed, it would nevertheless be necessary to reject them, because they are merely possible: therefore we will not lay any real Stress upon the Conjectures even of Sir *Isaac Newton* himself.

But we must not rely on Conjectures.

If I speak of them, it is rather to publish the History of his Thoughts, than to draw the least Conclusion from his Ideas, which

I look upon as the Dreams of a great Man. He did not at all build upon them himſelf: He was contented with Facts, without daring to determine any thing concerning their Cauſes.   Let us paſs to the other Diſcovery, the Agreement which exiſts between the Rays of Light and the Notes in Muſick.

CHAP.

CHAP. XIV.

Of the Resemblance between the seven Primitive Colours and the seven Notes in Musick

IT was you know perceived, a very long Time before *Descartes*, that a Prism exposed to the Sun exhibits the Colours of the Rainbow. Colours had often been seen to paint themselves upon Linnen, or upon white Paper, in an Order which is always the same. 'The Curious soon proceeded, from Experiment to Experiment, even to measure the Space that is occupied by every one of these Colours. At last it was found, that these Spaces are the same with regard to one another, as those of the Lengths of a Cord, that expresses the seven Notes in Musick. I had often heard it said, that *Newton* had taken from *Kircher* this Discovery of the Analogy between Light and Sound. *Kircher* indeed, in his *Ars Magna Lucis & Umbrae*, and in others of his Works, denominates Sound the Ape of Light. Some Persons

A very remarkable Thing in Kircher.

L 3　　　　　　　sons

fons have inferred from hence, that *Kircher* was acquaintted with the Particulars in which they agree: but it is proper, to prevent a Miſtake, to lay before the Reader what he ſays, in his 146th and following Pages. " Thoſe, ſays he, who have a loud and " ſtrong Voice, partake of the Nature of an " Aſs: they are indiſcreet and petulant, as " Aſſes are known to be; and this Voice " holds a reſemblance with the black Co- " lour. Thoſe whoſe Voice is grave at the " firſt, and afterwards ſharp, partake of the " Ox: they are, like that Animal, dull and " cholerick, and their Voice anſwers to a " ſky-blue."

He takes care to ſtrengthen theſe fine Diſcoveries by the Teſtimony of *Ariſtotle*. This is all that Father *Kircher* teaches us, who was otherwiſe one of the greateſt Mathematicians, and moſt Learned Men of his Age; and it was thus, in a manner, that all thoſe who were merely Scholars reaſon'd at that Time. Let us proceed now to the Reaſoning of Sir *Iſaac*.

Manner of knowing the Proportions of the ſeven primitive Colours of Light.

There are, you well know, ſeven principal Rays in every Ray of Light, which have all their Refrangibility: every one of theſe Rays hath

hath its Sine, and every one of these Sines its Proportions with the common Sine of Incidence; observe what passes in these seven primitive Rays, which part by dividing in the Air.

It is not our Business here to consider, that even in the Glass all these Rays are scattered, and that every one of them there hath a different Sine : We must regard the Assemblage of Rays in the Glass as a single Ray, which has only the common Sine A, B. But in emerging from the Glass, every one of these Rays visibly separating from the rest, each hath its different Sine ; that of red (the least refrangible Ray) is described by the Sine C, B; that of violet (the most refrangible of all) by the Line C, B, D.
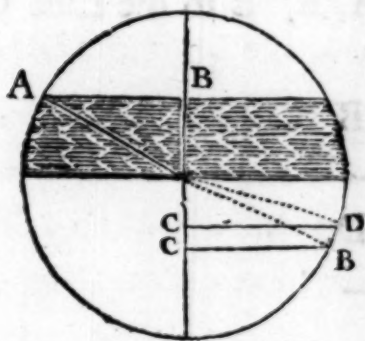
Those Proportions being settled, let us see

what

what is this Agreement, no lefs exact than fingular, between Colours and Mufick. Let the Sine of Incidence of the white Collection of Rays be to the Sine of Emergence of the red Ray, as this Line A, B, is to the Line B, C.

The Sine given in the Glafs

A   B
____   ____

The Sine given in the Air

B   C.
____   ____

Let the fame Sine of Incidence A, B, be to the Sine of Refraction of the violet Ray, as the Line A, B, is to the Line C, D.

A   B
____   ____

C   D.
____   ____

You perceive that the Point B is the Limit of the leaft Refrangibility, and D the Limit

4   of

A ——————————————————— I .   C

Red	Orang
appears From this Semi-circle to C	from C to F
45	27
$\frac{2}{2}$	$\frac{9}{16}$
re	ut
The grea: test Refran gibility of the Red. answers to	that of the Orang to
	ut

	C	H	G	F	E	B	D
	ed	Orange	Yellow	Green	Blue	Purple	Violet	
	ears this ircle C	from C to H	from H to G	from G to F	from F to E	from E to B	from B to D	
		27	48	60	60	40	80	=360
		$\frac{9}{16}$	$\frac{3}{5}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{8}{9}$	1
		ut	si	la	sol	fa	mi	re
	grea= Refra= lity of Red. ers to	that of the Orange to	that of the Yellow to	that of the Green to	that of the Blue to	that of y Purple to	that of the Violet to	
		ut	si	la	sol	fa	mi	re

of the greateſt : the ſmall Line B, D, con-
tains then all the Degrees of Refrangi-
bility of the ſeven Rays. Double now the
Line I, D, in the Scheme anſwering B, D, a-
bove, ſo that I, may become the middle, as
in this Figure or the Scheme annexed.

A I C H G F E B D.

Then the Length from A to C makes the
red ; the Length from A to H, the orange ;
that from A to G, the yellow ; that from
A to F, the green ; that from A to E, the
blue ; that from A to B, the purple ; that
from A to D, the violet. Now the Spaces
here given are ſuch, that every Ray may be
refracted, a ſmall matter more or leſs, in e-
very one of theſe Spaces, but can never go
beyond the Space preſcribed it: the violet
Ray will play between B and D, the red
Ray between C and I, and ſo of the reſt; the
whole in ſuch Proportion, that if you divide
the Length from I to D into 360 Parts,
every Ray ſhall have to itſelf the Dimenſions
that are exhibited in the large Scheme here-
unto annexed. Theſe

*The Ana-
logy be-
tween the
Notes in
Musick and
the seven
Colours.*

These Proportions are precisely the same as those of the Notes in Musick. The Length of the Cord, which, being stretched, shall sound *Re*, is to the Cord which shall give the Octave of *Re*, as the Line A, I, which gives the red in I, is to the Line A, D, which gives the violet in D : so that the Spaces which mark the Colours, in this Figure, mark also the Notes in Musick.

The greatest Refrangibility of the violet answers to *Re* ; the greatest Refrangibility of the purple, to *Mi* ; that of the blue, to *Fa* ; that of the green, to *Sol* ; that of the yellow, to *La* ; that of the orange, to *Si* ; that of the red, to *Ut* ; and, in a Word, the least Refrangibility of the red agrees with *Re*, which is the highest Octave. And one may form a compleat Idea of all these Proprieties, by casting his Eyes on the Table which I have drawn up, and which he will find over against the Observations in the preceding Page.

There is another Resemblance between Sounds and Colours, which is, that the most distant Rays, the violet and the red, strike our Eyes at the same Time, and that the most distant Sounds, the gravest and the

sharpest,

sharpest, come also to our Ears with equal Velocity. I do not mean by this, that we see and hear Things at the same Distance in the same Time; for Light makes an Impression on us, at least six hundred thousand times sooner than Sound; but the Sense is, that blue Rays, for Example, come not from the Sun to our Eyes sooner than red Rays, in like manner as the Sound of the Note *Si* does not reach our Ears sooner than that of the Note *Re.*

This Analogy between Light and Sound gives room for a Suspicion, that all Things in Nature have secret Relations, which perhaps may be discovered hereafter. It is already certain, that there is an Agreement between *Feeling* and *Sight*, since Colours depend upon the Configuration of Parts *. It is even maintained, that there have been Persons who were born blind, that could by their Feeling distinguish the Difference between white, black, and some other Colours.

An ingenious Philosopher has attempted to push this Relation between Seeing and Hearing farther, perhaps, than it may seem

* Or as before on the Thickness of their Surfaces.

per-

permitted for Men to proceed. He has con-
trived an ocular Harpsicord, which is to
exhibit a Succession of harmonic Colours, as
our Harpsicords do of Sounds : He has work'd
at it with his own Hands, and pretends that
in Time he shall be able to play Tunes to the
Eyes. Doubtless we cannot but thank a
Man, who takes such Pains to introduce
new Sciences, and new Pleasures among us:
There have been Countries, where he would
have received a publick Recompence. It is
certainly to be wished, that this Invention
may not be, like so many others, a very in-
genious, but unprofitable Effort. This ra-
pid Passage of a great many Colours before
the Eyes, it is to be feared, will be more
likely to astonish, dazzle, and fatigue the
Sight. Our Eyes, perhaps, may have need
of Repose, in order to enjoy the Agreeableness
of Colours. It is not enough to propose
a Pleasure to us ; Nature must have made us
capable of receiving that Pleasure. In a
Word, it is Experience alone that must justi-
fy this Invention. Mean while, methinks
every equitable Judge cannot but praise the
Efforts of such a Genius, as endeavours to

en-

enlarge the Carrier of Arts, and that of Nature.

We will not extend this Introduction concerning Light any farther; perhaps we have already said too much of it in a Treatise of Simple Elements: but the greatest Part of these Truths are new to most Readers. Before we go on to the other Part of this Philosophy, let us remember, that the Theory of Light hath something in common with the Theory of the Universe, on which we are now to enter. This Theory is, that there is a kind of Attraction observed between Light and Bodies, as well as among all the Orbs of our Universe, which we are next to consider. These Attractions are discovered by different Effects; but, in brief, Attraction is always a Tendency of Bodies to one another, without any apparent Impulsion.

All this Theory of Light has Relation to the Theory of the Universe.

Among so many Properties of Matter, such as those Fits of Transmission and Reflection of Light, that Repulsion which Light meets with in the Void, in the Pores of Bodies, and about their Surface; among all these Properties, I say, we ought chiefly to fix our Attention to that Power by which the Rays

are

are reflected and broken, to that Force by which Bodies act upon Light, and Light upon Bodies, without ever touching each other.

Matter has more Properties than has been imagined. These Discoveries may serve, at least, to render us extremely circumspect in our Decisions concerning the Nature and Essence of Things. Without the Sense of Feeling, we could have no Idea of the Extension of Bodies; without our Eyes, we could not think of such a Thing as Light; if we had never moved ourselves, we could never have believed the Mobility of Matter * : the small Number of Senses which God has given us, can discover to us but a few of the Properties of Matter. Our Reason supplies the want of other Senses, and teaches us that Matter has yet other Attributes, as Attraction and Gravitation. In all Probability it has many more belonging to its Nature, of which Philosophy, perhaps, may hereafter give some Ideas to Mankind.

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* Some think actual Motion might be known, by seeing Bodies change their Distance from one another when we are at rest.

CHAP.

CHAP. XV.

*Introductory Ideas concerning Gravity
and the Laws of Attraction: That
the Opinion of a subtil Matter, Vor-
tices, and a Plenitude, ought to be
rejected* *.

A N intelligent Reader, who shall have
considered with Attention these wonder-
ful Properties of Light, convinced by Expe-
rience that they are not produced by any
known Impulse, will doubtless be impatient
to know more of this new Power which we
have spoken of under the Name of *Attrac-
tion,* and which must needs act more sensibly
upon all other Bodies than upon that of
Light. That we may not any more be
frighted with Terms, let us examine simply
the Facts.

I shall make use indifferently of the Words *Attrac-
tion.*
Attraction and *Gravitation,* in speaking of
Bodies, whether they sensibly tend towards one
another, or turn in immense Orbs round one
common Centre, or fall upon the Surface of

* But not that subtile Æther which Sir *Isaac* makes the
Cause of Attraction, Refraction, Animal Motion, &c.
which pervades the Universe.

the

the Earth, or unite to compose solid Bodies, or, lastly, globify themselves in Drops to form Liquids. Let us enter upon our Subject.

All known Bodies gravitate; and the Notion of specifick Levity has been a long Time counted among the acknowledg'd Errors of *Ariſtotle* and his Followers.

Since the Invention of the famous pneumatic Engine, or Air-Pump, we have been in a much fairer Way to know the Gravity of Bodies; for when they fall in the Air, the Particles of that Element senſibly retard the downward Motion of those Bodies which have large Surfaces and little Subſtance; but in that Machine deprived of Air, Bodies being abandon'd to that Force, whatever it be, which precipitates them without Obſtacle, do fall according to their whole Weight.

The pneumatic Engine, invented by *Ottoguerick*, was soon after brought to Perfection by Mr. *Boyle*; it was furniſhed with Glaſs Recipients much longer than at firſt, and these were entirely deprived of Air. In one of these long Recipients, compoſed of four Tubes, the whole together being eight Foot high, were suſpended at the Top, by a Spring,

An Experiment which demonstrates a Vacuum, and the Effects of Gravitation.

Pieces

Pieces of Gold, Bits of Lead, Scraps of Paper, and Feathers; the Queſtion was, to know what would be the Conſequence, when the Spring was let fly. The philoſophical Gentlemen foreſaw, that the whole would come to the Bottom at the ſame Time: But much the greateſt Number were confident, that the moſt ſolid Bodies would fall with far greater Velocity than the Reſt. The Multitude, which is almoſt always in the wrong, was aſtoniſh'd at the Event; for in every Experiment that was made, the Gold, the Lead, the Paper, and the Feathers, deſcended equally ſwift, and came to the Bottom of the Recipient in one and the ſame Inſtant,

Thoſe who ſtill held for the *Plenitude* of *Deſcartes*, and for the pretended Effects of the ſubtile Matter, could not give any good Reaſon for this Fact; for Facts were the Rocks on which they ſplit. If there was an abſolute Plenitude, tho' we allowed there might notwithſtanding be ſuch a Thing as Motion, (which is abſolutely impoſſible) at leaſt this pretended ſubtile Matter muſt exactly fill all the Recipient; it muſt be there in as great Quantity as Water, or Mercury, that

M   might

might have been put there; it muſt reſiſt the
Pieces of Paper, according to their Surfaces,
and let the Gold and the Lead deſcend much
ſooner: But this Deſcent is perforṃed in the
ſame Inſtant; therefore there is nothing in
the Recipient that reſiſts; therefore the pre-
tended ſubtile Matter cannot produce any
ſenſible Effect in this Recipient; therefore
there is ſome other Power which cauſes Gravity.

It would be in vain to ſay, that there may
poſſibly remain a ſubtile Matter in the Reci-
pient, becauſe it is penetrated by the Light:
There is a great deal of Difference in the
two Caſes. The Light, which is in this
Glaſs Veſſel, does not fill, at the moſt, the
hundred thouſandth Part of it; but accord-
ing to the *Carteſians*, we are to imagine that
their ſubtile Matter fills it much more com-
pleatly than if I ſuppoſed it full of Gold;
for there is a great deal of Vacuum in Gold,
but they admit none in ſubtile Matter.

Bodies gra-
vitate in
proportion
to the
Quantity
of their
Matter.

Now by this Experiment, the Piece of
Gold, which weighs an hundred thouſand
Times as much as the Paper, deſcends with

* Yea, the Needle in it would turn to its Point..
† Sure there is Light at each Part where a Mite is viſible
the

the same Velocity as the Paper; therefore
the Power, which makes it descend, acts an
hundred thousand Times more forcibly upon
the Gold, than upon the Paper; in like man-
ner as a hundred Times more Strength is re-
quisite in my Arm to move an hundred
Pounds, than to move one Pound. That
Power then, which is the Cause of Gravita-
tion, acts in direct Proportion to the Quantity
of Matter in Bodies. In Effect, it acts so
according to the Quantity of Matter in Bodies,
and not according to their Surfaces, that a
Pound of Gold reduced into Dust, will weigh
precisely as much as the same Quantity beat
out into Leaves. The Figure of Bodies makes
no Alteration in their Gravity; the Power of
Gravitation then operates upon the internal
Nature of Bodies, and not in proportion to
their Superficies.

This Power does not reside in the pretended *Whence the*
subtile Matter, of which we shall speak in *Power of*
Gravita-
the next Chapter: That Matter must be a *tion pro-*
ceeds.
Fluid; and every Fluid acts upon Solids in
proportion to their Superficies. Thus the
Vessel presenting a smaller Surface at her Prow,
cuts through the Sea which would resist her

Sides.   Now if the Superficies of a Body be
the Square of its Diameter, the Solidity of
this Body is the Cube of the same Dia-
meter : But the same Power cannot act at
one Time in proportion to the Cube and the
Square ; therefore the Gravity of Bodies is
not the Effect of this Fluid.   Besides, it is im-
possible that this pretended subtile Matter
should, on the one Side, have so much Force
as to precipitate a Body from the Height of
54000 Feet in a Minute (for such is the De-
scent of Bodies) and that, on the other, it
should be so weak, as not to hinder the lightest
Wooden Pendulum to proceed from Vibra-
tion to Vibration in the pneumatic Engine,
which is supposed to be compleatly filled with
this imaginary Matter.

I shall make no Scruple then to affirm,
that if any Impulse should ever be discovered,
which is truly the Cause of the Tendency of
Bodies towards a Center, the Cause, in a
Word, of Gravitation and Attraction, that
Impulse will be altogether of a different Na-
ture from any Thing we are acquainted with *.

* Every Body must tend to the Center of the Earth, if
there be a Vacuum or little Resistance there.

There

There is one primary Truth then, that was pointed out elsewhere, and has been proved in this Chapter, that there is a Power, which occasions all Bodies to gravitate, in exact Proportion to the Quantity of their Matter.

If it be actually enquired, why one Body *Why one* is more ponderous than another, the single *weighs* and only Reason of it will easily be found : *more than another.* It will be concluded, that this Body must have more Solidity, more Matter under the same Extent : Thus Gold is heavier than Wood, because there is in Gold much more Matter, and much less Vacuity, than in Wood.

Descartes and his Followers maintain, that *The System* one Body is heavier than another without *of Descartes cannot* containing more Matter. Not content with *account for it.* this Idea, they support it by another altogether as false : They admit a grand Vortex, Tourbillon or Whirlpool, of subtile Matter, encompassing our Globe ; and it is this grand Vortex, say they, that in its Circulation drives all Bodies towards the Center of the Earth, and impresses on them that Quality which we call Gravity.

It is true, they have not given any Proof

of this Affertion*. There is not the leaft Experiment, not the leaft Analogy in Things of which we have any Knowledge, whereon to eftablifh even a flight Prefumption in favour of this Whirlpool of fubtile Matter; fo that for this very Reafon alone, that this Syftem is a mere Hypothefis, it ought to be rejected: Neverthelefs, it was on no other Account that it obtained Credit. This Vortex was conceived without Difficulty; an indefinite Explanation of Things was given, by pronouncing the Words *fubtile Matter*; and when the Philofophers were fenfible of the Contradictions and Abfurdities that cleav'd to this philofophical Romance, they dream'd rather of correcting than abandoning it.

Huygens and many others have made in it a thoufand Corrections, of which they themfelves confefs the Infufficiency: But what fhall we put in the Place of thefe Tourbillons, and this fubtile Matter? It was this too common Way of Reafoning, more than any Thing, that confirm'd Men in the Error they had embraced. But we ought to abandon what is manifeftly falfe and infupportable,

* This is a great Condefcention. *of who?*

as

as well when we have nothing to fubftitute in its Room, as when we have the Demon-ftrations of *Euclid* to put in its Place. An Error is neither more nor lefs an Error, whe-ther the Lofs of it be or be not, fupplied by Verities. Ought I to admit the horrid No-tion of a Vacuum in a Pump, becaufe I am not yet able to judge, by what Mechanifm the Water rifes in that Pump*?

Before we proceed any farther then, let us take upon us to prove that the Vortices of fubtile Matter have no Exiftence; that the Idea of Plenitude is not lefs chimerical; that therefore the whole Syftem, founded on thefe Imaginations, is no more than an inge-nious Romance, without the Appearance of Truth. We will enquire firft, what is meant by thefe Vortices; and afterwards examine, whether or no a Plenitude be poffible.

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* *Defcartes* does not require us to believe a Vacuum in a Pump, he explains it by a Plenum; for the Sucker be-ing drawn upwards, preffes the Matter above it, which Preffure is continued to the Surface of the Water at the Bottom of the Pump, which preffes the Water up the fame Inftant, all being full.

M 4 CHAP.

C H A P. XVI.

That the Vortices and Plenitude of Defcartes are impoffible, and confequently that there is fome other Caufe of Gravity.

DESCARTES fuppofes an immenfe Heap of imperceptible Particles, which carries the Earth round, with a rapid Motion from Weft to Eaft, and which from Pole to Pole moves parallel with the Equator. This Vortex of Matter, which extends beyond the Moon, and drags her alfo along with it in its Courfe, is enclofed in another Vortex yet much more extenfive, which touches another yet larger, without being confounded with it; and fo on.

Proof of the impof- fibility of the Vor- tices.

If this were fo, 1ft, the Vortex which is fuppofed to move round the Earth from Weft to Eaft, would drive the Bodies that are upon the Earth from Weft to Eaft alfo* : Now all Bodies, in falling, defcribe a Line, which, being prolonged, would pafs very near thro' the Centre of the Earth : therefore this Vortex has no Exiftence.   2dly,

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* Not if the Earth move along with it as it does with our Atmofphere which moves but very little fafter.

2dly, If the Circles of this pretended Vor-
tex moved and acted parallel to the Equator,
all Bodies muſt fall perpendicularly, every one
under that Circle of the ſubtle Matter to
which it anſwers: a Body in A, near the
Pole P, muſt, according to *Deſcartes*, fall
in R *.
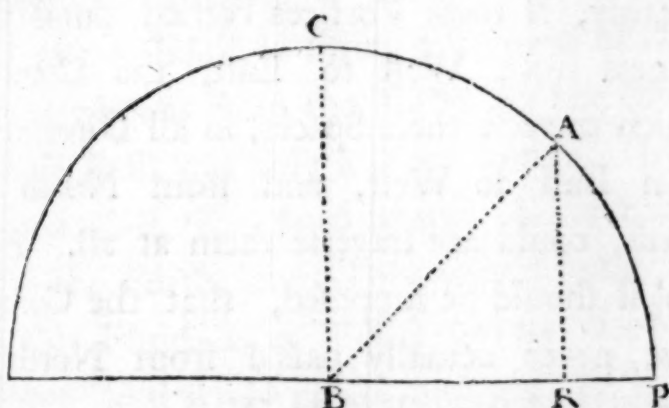
Whereas it falls, within a Trifle, according
to the Line A, B, which makes a Difference
of about 1400 French Leagues; for we may
compute near that Number from the Point
R, to the Equator of the Earth B; there-
fore this Vortex hath no Exiſtence.

3dly, If this Vortex of Matter around the
Earth, and thoſe other pretended Vortices a-
round Jupiter, Saturn, *&c.* exiſted; all theſe

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* This is an Argument of ſome Weight, except we ſup-
poſe that Bodies tend to the Center, where there is leſs
Reſiſtance, as the Winds do. *why this Suppoſition?*

2   im-

*all Bodies fall perpendicularly to the Tang of that
part of the Earth Surface*

immenfe Vortices of fubtile Matter, rowling fo rapidly in different Directions, could never fuffer any one Ray of Light, darted from a Star, to come to us in a right Line.   Now it has been proved that thefe Rays arrive in a very fhort Time, confidering the immenfe Way they come: Therefore there are no Vortices.

4thly, If thefe Vortices carried round the Planets from Weft to Eaft, the Comets, which traverfe thefe Spaces, in all Directions, from Eaft to Weft, and from North to South, could not traverfe them at all.   And tho' it fhould be fuppofed, that the Comets have never actually pafs'd from North to South, and from Eaft to Weft, yet nothing would be gain'd by this Evafion; for it is known, that when a Comet is feen in the Region of Mars, of Jupiter, of Saturn, it moves incomparably fwifter than Mars, than Jupiter, or than Saturn;   therefore it cannot be carried round by the fame Bed of fluid Matter which is fuppofed to carry round thofe Planets *; and therefore no Vortices.

5thly, Thefe Vortices muft be either e-qually denfe, equally compact with the Pla-

* Except there be a fufpended Force,

nets,

nets, or they muſt be more denſe, or, finally, they muſt be leſs denſe. In the firſt Caſe, the pretended Matter, which encompaſſes the Moon and the Earth, being ſuppoſed equally denſe with the ſame Bulk of Earth, we ſhould experience the ſame Reſiſtance, in lifting, for Inſtance, a Cubic Foot of Marble, as we ſhould in lifting a Column of Marble as high as from the Earth to the Moon, whoſe Baſis was only a Foot ſquare. In the ſecond Caſe, the fluid Matter being heavier than the Earth, our Globe would ſwim upon this Fluid, as a Veſſel ſwims upon the Water, and could not be plunged, as is pretended, into the ſubtile Matter. In the third Caſe, the Fluid being leſs denſe, leſs weighty than the Earth, this Fluid could never ſuſtain it, for the ſame reaſon as Water cannot ſuſtain Iron, nor any thing that weighs more than itſelf *: Therefore no Vortices.

6thly, If theſe imaginary Fluids had any Exiſtence, all the Order of rhe Celeſtial Orbs would be inverted: The Sun, which turns upon its own Axis, would ſoon loſe its Mo-

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* If there be a Plenum no Body is more denſe than another, only it contains more of Homogeneous Matter.

tion

tion from the Obstruction of this Fluid; and not one of the Planets would keep the Course it now holds, would have the Motion it now has, or would long have any Motion at all.

7thly, The Planets carried round in these Vortices could move circularly only, because the Vortices, at equal Distances from the Center, must be equally dense; but the Planets move in Eclipses, and there cannot be carried round in any such Vortices; therefore no such Vortices exist.

8thly, The Earth has her Orbit, which she passes thro', beween the Orbit of Venus and that of Mars: All these Orbits are elliptical, and have the Sun for their Center: Now when Mars, Venus, and the Earth, are nearest one to another, the Matter of this pretended Torrent, which carries round the Earth, must be much more compressed than at other Times: This subtile Matter should then precipitate its Course, as a River that is straitened in its Banks, or flows under the Arches of a Bridge; and, consequently, should then force the Earth on with much greater Rapidity, than when it is in any other Position: But, on the contrary, it is just

then

then that the Motion of the Earth is more
retarded than at other Times *.
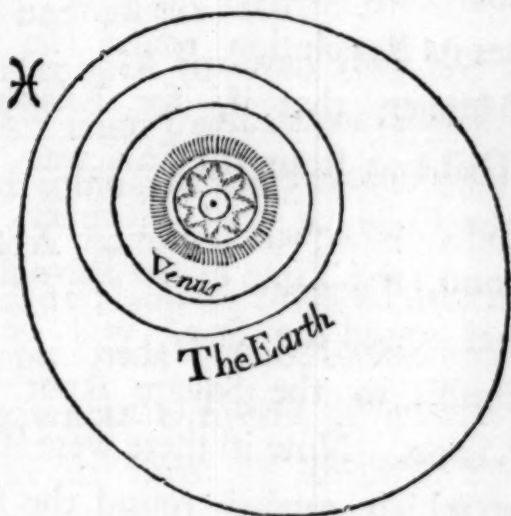
When Mars appears in the Sign Pisces, that
Planet, the Earth, and Venus, are nearly in
the Proximity here represented; and then
the Sun seems to be retarded for some Mi-
nutes, that is, the Earth is retarded: It is
demonstrably impossible then, that there
should be Torrents of Matter which carry
round the Planets: Therefore the Vortices
have no Existence.

9thly, Among the more abstracted De-
monstrations, which destroy the Being of
these Vortices, we will chuse the following.

* This would hold good if the Planets were fixed as
the Pillars of a Bridge.

By

By one of *Kepler*'s Fundamental Laws*, every Planet defcribes equal Areas in equal Times: By another Law not lefs certain, every Planet makes its Revolution round the Sun in fuch a Manner, that if, for Example, its middle Diftance from the Sun was 10, by taking the Cube of that Number, which makes 1000, the Time of the Revolution of that Planet round the Sun, will be found proportionable to the Square Root of the Number 1000. Now if there were Torrents of Matter which carried round the Planets, thefe Torrents could not follow thefe Laws; for the Swiftneffes of the Torrents muft be proportional to their Diftance from the Sun, and, at the fame Time, to the Square Roots of thofe Diftances; which is incompatible.

To fum up the whole; every one fees what muft happen to two Fluids, circulating in oppofition the one to the other: They would neceffarily be confounded together, and form a Chaos, inftead of maintaining an Order in Nature. This alone, would at once have expofed the Cartefian Syftem to the utmoft

* The Period of each Part of the Vortex is as the Cube of its Diftance.

Ridicule, if the Love of Novelty, and an habitual Difufe of free and impartial Examinations, had not prevailed.

We are now to prove that the Plenitude, *Proof against a Plenitude.* in which thefe Vortices are fuppofed to move, is as impoffible as the Vortices themfelves.

1ft, A fingle Ray of Light, which does not weigh any thing near the hundred thoufandth Part of a Grain *, muft difcompofe the Order of the whole Univerfe, if it was to open its way to us thro' an immenfe Space, every part of which would not only refift of itfelf, but the whole Line of Matter which preffes on it.

2dly, Two hard Bodies, A and B, (we have already proved that there muft be hard Bodies,) touch one another at one Surface, and are fuppofed to be encompaffed with a Fluid, which preffes them on all fides: Now, when they are feparated, † it is clear that the pretended fubtile Matter muft arrive fooner at the Point A, where they divide, than at the Point B.

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* If his Atoms have any Weight, a Line of them to the Stars, or a Ray, will have confiderable Weight.

† Two polifhed Surfaces will not part, by which he proves a Plenum.
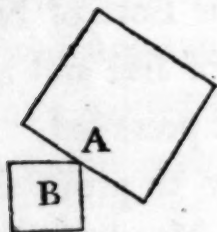
There

There is a Moment then, wherein there muſt be a Void at B ; therefore even in the Syſtem of the ſubtile Matter there is a Void.

3dly, If there was no ſuch Thing as Vacuity and Space, there could be no Motion, even in the Syſtem of *Deſcartes* himſelf. He ſuppoſes that God created the Univerſe full, conſiſting of ſmall Cubes * : Let there then be a given Number of Cubes, repreſenting the Univerſe, without their having the leaſt Interval between them : It is evident, that one of them muſt move out of the Place it occupies ; for if every one continues in its Place, there can be no Motion, becauſe Motion conſiſts in changing of Place, in moving from one Point of Space to another. Now who does not perceive, that one of theſe Cubes cannot quit its Place, without leaving a Vacuum at the Inſtant it goes out of it ;

* See rather *Deſcartes* himſelf.

ſince

since it is clear that this Cube, in turning it-self round, muft prefent its Angle to the Cube it touches, before that Angle can be beat in Pieces ? At that Time then there is Space between thefe two Cubes ; therefore, even in the Syftem of *Defcartes* himfelf, thefe cannot be Motion without a Vacuum.

4thly, If all was full, as *Defcartes* would have it, we ourfelves fhould feel an infinite Refiftance in walking, whereas we perceive no other than that of the Fluids in which we are : That of Water, for Example, refifts 860 Times, and that of Mercury 14,000 Times, more than that of Air. Now the Refiftances of Fluids are in proportion to the Squares of Velocities: Thus if a Man, in a Third of Time, makes his way thro' a Foot of Mercury, which refifts him 14,000 Times more than Air ; if this Man, in the next Third, move twice as far, the Mercury in this Third, will refift in proportion to the Square of 2 multiplied by 14,000 ; a Refif-tance 56,000 Times more powerful than that of Air: If all were full, it would be abfolutely impoffible to walk a ftep, to breathe, &c. *

* Refiftance is not according to the Quantity of Mat-ter, but to the yielding of the Particles, or parting more or lefs eafily.

N   5thly,

5thly, The *Cartesians* have endeavour'd to elude the Force of this Demonstration, but they had no other way of doing it, than by advancing a manifest Error. They pretend, that this infinite Torrent of subtile Matter penetrating all the Pores of Bodies, cannot hinder their Motion. They did not reflect, that every Body, which moves in a Fluid, feels a Resistance in proportion to the Extent of Surface it opposes to this Fluid: Now the more Pores there are in a Body, the larger is its Surface: So that the pretended subtile Matter, by clogging up all the Inside of a Body, must oppose the Motion of that Body much more forcibly, than by touching only its outward Superficies. This is capable of the most undeniable Demonstration.

6thly, All Bodies in a Plenitude would be equally weighty: It is impossible to conceive that a Body bears upon me, and presses me, but by its Quantity of Matter; a Pound of Gold Dust weighs as much on my Hand, as a Lump of Gold of a Pound. In vain the *Cartesians* answer, that the subtile Matter penetrating the *Interstitia* of Bodies, has no Weight, and that we ought to esteem nothing

thing weighty but what is not subtile Matter. This Opinion, in *Descartes,* is no less than a direct Contradiction; for, according to him, it is the pretended subtile Matter alone that causes the Gravity of Bodies, by forcing them towards the Earth *: This subtile Matter it-self then gravitates upon these Bodies; and if it doth so, there can be no Reason why one Body should be more weighty than ano-ther, since all being equally full, all must be equally in Quantity of Matter, whether So-lids or Fluids: A Plenitude then, is a Chi-mæra; there is a Vacuum therefore, and no-thing can be done in Nature without a Va-cuum; therefore Gravity is not the Effect of a pretended Vortex, in an imaginary Pleni-tude.

* But it does not thence follow, that that subtile Mat-ter gravitates; for tho' Matter descending in one Tube forces it up in another, it does not therefore go up tself.

N 2   CHAP.

C H A P. XVII.

What is meant by Vacuity *and* Space, *without which there could be neither Gravity nor Motion.*

Objections against a Void.

THOSE who cannot conceive a *Void*, object, that this Void muſt be nothing, that nothing cannot have Properties, and therefore, that there can be no Operation in the Void.

Anſwer.

We anſwer, It is not true that a Vacuum is nothing ; it is the Place of Bodies ; it is Space ; it hath Properties ; it is extended in Length, Breadth, and Depth ; it is penetrable, inſeparable, *&c.* I cannot, indeed, form in my Head an Image of extended Space, as I can of extended Body ; but I can demonſtrate to myſelf that this Space exiſts. I cannot repreſent to myſelf, in Geometry, an Infinity of Circles paſſing between a Circle and a Tangent ; but I can nevertheleſs demonſtrate to myſelf that the Thing is true in Geometry, which is ſufficient to my Purpoſe. I cannot conceive what it is within

me

me that thinks, yet I am convinced that something thinks within me. In like manner I demonstrate to myself the Impossibility of a Plenitude, and the Necessity of a Void, without having any Image of a Void : For I can have no Image but of that which is corporeal, and Space is not corporeal. It is one thing to represent an Idea to one's self, another thing to conceive a Truth : I have a full Conception of Space; and the *Epicurean* Philosophers, who were wrong in every thing else, conceived it very well.

There was no other Way to answer this Argument, than by saying that Matter is infinite. This is what many antient Philosophers have affirmed, and what *Descartes* after them has revived.

But on what Foundation do they imagine that Matter is infinite? Only on another Supposition, which they are pleased to make. They say, Extension and Matter are the same Thing : We cannot conceive any Limits to Extension; therefore we must admit that Matter is infinite.

Matter is not infinite.

This proves how easily Men bewilder themselves, when they reason only on Suppositions.

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It is falſe that Extenſion and Matter are the ſame Thing : All Matter is extended ; but all Extenſion is not Matter. *Deſcartes*, by advancing that there could be no Extenſion but of Matter, advanced a very unphiloſophical Notion; for we know nothing at all of what Matter is ; we know only ſome few of its Properties ; and no Man can deny, but Millions of other extended Subſtances may exiſt, different from that which we call Matter : Now where muſt theſe Subſtances have their Being, if not in Space ?

Beſides this Error, *Deſcartes* contradicts himſelf again ; for he admits a God. Now where is this God ? He is not in a mathematical Point ; he is immenſe : What is his Immenſity, is it not immenſe Space?

With regard to the pretended Infinity of Matter, that Idea hath as little Foundation as the Vortices. We have ſeen the abſolute Neceſſity of a Void in the Order of Things, and that therefore Matter, as it fills not all Space, is not infinite. But what are we to *Diſcuſſion of this Truth.* underſtand by an infinite Matter ? For the Term *Indefinite*, uſed by *Deſcartes*, either muſt be explained by this, or it ſignifies nothing

at

at all. Do they mean, that Matter is essentially infinite in its own Nature? If so, then Matter is God. Do they mean, that God has created it infinite? Whence do they know that? Do they mean, that Extension and Matter are the same Thing? The Falsity of that Argument has been sufficiently proved.

The Existence of infinite Matter, is, at the Bottom, a Contradiction in Terms. But, it will be said, you admit an Immensity, and Infinity of Space; why do you not admit the same concerning Matter? Here lies the Difference: Space exists of Necessity, because God necessarily exists; it is immense; it is, like Duration, a Mode, an infinite Attribute of a necessary, infinite Being. But Matter is nothing of all this: It does not necessarily exist; and if such a Substance were infinite, it would be either an essential Attribute of God, or God himself: But it is neither the one nor the other; therefore cannot be infinite.

I shall conclude this Chapter with a Remark, which to me seems worthy of the utmost Attention: *Descartes* admitted a God, *A singular Remark.*

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* If Space be an Attribute it must be in a Subject; not in God, for he is in Space, *Page* 182. *Line* 12.

the

the Creator and Cause of all Things, but he denied the Possibility of a Void : *Epicurus* denied that there was a God, the Creator and Cause of all, but admitted a Void. Now it was *Descartes* who, according to his Principles, ought to have denied a divine Creator, and it was *Epicurus* who should have admitted him. We will prove it evidently.

For if a Void was impossible*, if Matter was infinite, if Extension and Matter were the same Thing, it would follow that Matter must be necessary : Now if Matter was necessary, it must exist of itself by an absolute Necessity, inherent in its primitive Nature, antecedent to all Things: Matter would then be God ; therefore he, who maintains the Impossibility of a Void*, ought not, if he reasons consequentially, to admit any other God than Matter.

On the contrary, if there be a Void, then Matter is not a necessary self-existent Being, consequently, it was created ; consequently, there is a God. It was the Part of *Epicurus* therefore to believe a God, and of *Descartes*

* This is not for Void being in the Pores of Bodies.

to

to deny one *. Wherefore then, on the contrary, is *Descartes* continually speaking of a God, the Creator and Preserver of all Things, and why does *Epicurus* reject such a Being ? for this very Reason, that Men, in their Sentiments, as in their Conduct, seldom follow their own Principles ; that their Systems, as well as their Lives, are Contradictions.

We learn from all that has been said, that *Conclusion.* Matter is finite, that there is a Void, that is to say, *Space* †, and even incomparably more Space than Matter in our World ; for the Quantity of Pores is much more than that of Solids. We conclude that a Plenitude is impossible ; that the Vortices of subtile Matter are equally so ; that *Descartes*'s Cause of Gravity and Motion is a Chimera.

We have been taught, by the Experiment in the pneumatic Machine, that there must be a Power which occasions the Descent of Bodies towards the Centre of the Earth, that is, which gives them their Gravity ; and that this Power must act in proportion to the Quantity of Matter of which Bodies consist :

* He thought it no Reason to disbelieve a God, because he could not comprehend his Works.

† Where Matter is there is Space, tho' occupied.

We

We are now to enquire, what are the Effects of this Power ; for if we can make any Dif- covery of its Effects, the Existence of it will be evident.   Let us not begin with affign- ing Causes, and forming to ourselves Hypo- theses ; that is the sure Way to wander from the Mark : Let us pursue, Step by Step, that which really passes in the System of Na- ture*. We are Voyagers, arrived at the Mouth of a River, and must labour up the Stream, before we guess at the Situation of the Source.

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* The Experiment seen must not be explained by your Principle, because I can give no other.

CHAP.

CHAP. XVIII.

*Gravitation demonstrated from the Dis-
coveries of* Galileo *and* Newton:
*That the Moon revolves in her Orbit
by the Force of this Gravitation.*

GALILEO, the Restorer of Reason in *Laws of
the Gravi-
Italy*, discovered this important Propo- *tation of
Bodies
found by
Galileo.* sition, That heavy Bodies, which descend to
the Earth (allowing for the small Resistance of
the Air) have a Motion accelerated in a cer-
tain Proportion, of which I shall now endea-
vour to give a concise and clear Idea.

A Body abandoned to itself from the Top
of the Tower, descends, in the first second,
a Space which is found equal to 15 *Paris*
Feet, according to the Discovery of *Huygens*,
the great Mathematician. It was thought
before *Galileo*, that this Body in two seconds,
would have passed thro' only twice the same
Space, and that thus it would fall 150 Feet
in ten seconds, and nine hundred Feet in a
Minute. This was the general Opinion, and
a very probable Opinion it was to a Person

who

who did not examine things clofely. Nevertheless, it is certain that in a Minute this Body would fall 54,000 Feet, and 216,000 Feet in two Minutes.

Let us fee how this Progrefs, which at firft aftonifhes the Imagination, is performed neceffarily, and with Simplicity. A Body is precipitated with its own proper Weight: That Power, whatever it be, which animates it to defcend fifteen Feet in the firft fecond, acts equally at every Inftant; for nothing having changed it, it muft of neceffity continue the fame: Thus at the next fecond, the Body will have the Force which it has acquired in every Inftant of the firft, and the Force which it experiences every current Inftant. Now by the Force which animated it in the firft fecond, it defcended 15 Feet; it hath ftill that Force then, when it defcends the next fecond. It hath befide that the Force of 15 other Feet, which it acquired by defcending this firft fecond, and that makes 30. It muft ftill have alfo in the fecond fecond (nothing being changed) the Power of falling 15 Feet which makes 45. By the fame Reafon, this

Body

Body will descend 75 Feet at the third second; and so proportionately in the rest.

Hence it follows, 1st, That in equal Times infinitely small, a moving Body acquires Degrees of Velocity infinitely small, which accelerate its Motion towards the Center of the Earth, provided it meets no Resistance.

2dly, That the Degrees of Velocity which it acquires, are in proportion to the Degrees of Time it employs in descending.

3dly, That the Spaces it passes through, are as the Squares of these Times, or of these Degrees of Velocity.

4thly, That the Progression of Spaces passed through by this moving Body, are as the unequal Numbers 1, 3, 5, 7. This necessary Knowledge of a Phenomenon, that happens on every Side of us every Moment, shall be render'd sensible, even to those who may at first be a little embarrass'd with all these Proportions: They need only cast their Eyes, with a little Attention, on the Table annex'd, which every Reader may enlarge at his Pleasure.

It

Squares

Times in which the Body falls.	Spaces which it passes through in every Time.	Spaces passed over, which are as the Spaces of the Times.	Unequal Numbers, which mark the Progression of Motion, and the Spaces passed over.
1ft Second, one Velocity.	The Body defcends 15 Feet.	The Square of 1 is 1. The Body falls 15 Feet.	Once fifteen.
2d Second, two Velocities.	The Body defcends 45 Feet.	The Squares of two Seconds or two Velocities, is four. Four times fifteen are 60. The Body then has defcended 60 Feet, that is 15 in the firft fecond, and 45 in the fecond.	Three Times fifteen. Thus the Progreffion is from one to three in this fecond.
3d Second, three Velocities.	The Body defcends 75 Feet.	The Square of 3 feconds is 9: Nine Times 15 makes 135. The Body then has defcended 135 Feet in 3 Seconds.	Five Times fifteen. Thus the Progreffion is vifible according to the unequal Numbers 1, 3, 5, &c.

It is manifest at first Thought, that in every Instant infinitely small, the movable Body receives an accelerated Motion; since it appears, both by the Proposition and the Experiment, that this Motion augments continually. A slight Inspection of this little Table will demonstrate, that at the End of a Minute the Body will have descended 54,000 Feet, for 54,000 make the Square of 60 Seconds, multiplied by 15. Now 15 multiplied by the Square of 60, which is 3,600, the Product is 54,000.

These Experiments gave Birth to a new Conjecture, in reality well founded, but which nevertheless required a particular Demonstration. For, observing that a Body, of a Weight almost equal, descended 60 Times as fast at the End of 60 Minutes as it did during the first Minute, it was presumed that the Weight itself must vary, in some certain Proportion to its Distance from the Center of the Earth. Several great Men, who sought a new Road to the Knowledge of Nature, and among others the famous Lord *Bacon*, Chancellor of *England*, began also to suspect that there was a Gravitation, an Attraction of Bodies
dies

dies to the Center of the Earth, and of the Earth to Bodies. He propofed, in his excellent Book, *Novum Scientiarum Organum*, the making of Experiments with Pendulums upon the Tops of the higheft Towers, and at the Bottom of the deepeft Wells: For, faid he, if the fame Pendulums vibrate more rapidly at the Bottom of a Well than on the Top of a Tower, we muft conclude that Gravity, which is the Principle of thefe Vibrations, will be much more powerful at the Centre of the Earth, to which the Well is neareft. He attempted alfo to make Experiments of the Defcent of Bodies from different Elevations, and to obferve if they defcended lefs than fifteen Feet the firft fecond : But there never appeared any Variation in thefe Experiments, the Elevations and Profundities where they made them being of too little Confequence.

In this Uncertainty they continued, and the Idea of a Power acting from the Center of the Earth remained a random Conjecture.

Defcartes was acquainted with thefe Particulars, and even fpeaks of them in treating of Gravity : But Experiments, which alone could clear up this grand Queftion, were ftill wanting.

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wanting. The Syſtem of the Vortices hurried away this vaſt and ſublime Genius: It was his Pleaſure, in creating his Univerſe, to give the Direction of every thing to his ſubtile Matter, which he made the Diſpenſer of all Motion and all Gravity. By little and little *Europe* adopted his Syſtem, for want of a better.

At laſt in 1672, Mr. *Richer*, in a Voyage to *Cayenna*, near the Line, undertaken by Order of *Lewis* XIV. under the Protection of *Colbert*, the Father of all the Arts ; *Richer*, I ſay, among many Obſervations, found that the Pendulum of his Clock no longer made its Vibrations ſo frequently as in the Latitude of *Paris*, and that it was abſolutely neceſſary to ſhorten it by a Line, that is, eleventh Part of our Inch, and about a Quarter more *. *Experiment made by ſome Academicians, which conduced to this Diſcovery.*

Natural Philoſophy and Geometry were not then, by far, ſo much cultivated as at preſent. Who could have believed, that from this Remark, ſo trifling in Appearance, that from the Difference of the eleventh of our

* A Foot in Meaſure at *Paris* being more than an *Engliſh* Foot, ſo is their Digit or 12th Part of it more than our Inch, in proportion as 144 to 135.

O   Inch,

Inch, or thereabouts, could have fprung the greateft of phyfical Truths? It was found, at firft, that Gravity muft needs be lefs under the Equator, than in the Latitude of *France* *, fince Gravity alone occafions the Vibration of a Pendulum †.

The Earth higher in Proportion at the Equator than at the Poles.

In Confequence of this it was difcovered, that, whereas the Gravity of Bodies is by fo much the lefs powerful, as thefe Bodies are farther removed from the Center of the Earth, the Region of the Equator muft abfolutely be much more elevated than that of *France*; and fo muft be farther removed from the Center; and therefore, that the Earth could not be a Sphere. Many Philofophers, on occafion of thefe Difcoveries, did what Men ufually do, in Points concerning which it is requifite to change their Opinion; they oppofed the new-difcovered Truth. Many Doctors of the Church, even till the fifteenth Century, had

* Some think the Vibrations at the Equator are fewer than near the Pole, becaufe of the denfer Medium there, by the Multitude of Vapours at the Equator from the Sun's Heat: for in the fame Latitude the number of Vibrations change as the Medium in which

† Perhaps not the Number of them, but the Medium that refifts lefs or more.

believ'd

believ'd the Earth to be flat, longer from East to West than from North to South, and covered with the Sky, as a Vault, in the Form of a Tent. Their Opinion appear'd to them by so much the more certain, as they believed it founded upon the Bible. But a very little Time before the Discovery of *America*, a Bishop of *Avila* treated the Opinion of the Earth's globular Form as an Impiety, and an Absurdity. At last Reason, and the Voyage of *Christopher Columbus*, restored to the Earth its ancient spherical Form, which the *Egyptians* and *Chaldeans* had given it. People then passed from one Extreme to another; they believed the Earth a perfect Sphere, and that the Stars made their Revolution in a true Circle.

Nevertheless, from the Moment that they began to be certain of the Earth's diurnal Rotation upon its own Axis, they ought to have judg'd from that alone, that a Form entirely spherical could not belong to it. They need only have considered, that such a Rotation once in twenty four Hours must elevate the Waters of the Sea; that these Waters, being more elevated than the rest of

the Globe, would fall back upon the Land in
the Region of the Equator, and overflow it:
But the Waters have no such Fall; therefore
the solid Earth must be as much elevated as
the Waters. This Reasoning, so very simple,
so natural, escaped the greatest Genius's of
that Time; a certain Proof of the Strength
of Prejudice, that it did not permit even this
flight Examination. They still contested *Ri-
cher's* Experiment: They pretended, that the
Vibrations of our Pendulums were less fre-
quent towards the Equator, for no other Rea-
son but because the Heat lengthened Metal:
They perceived, that the Heat of the most
scorching Summer, would lengthen an Iron
Rod above thirty Feet long, about the ele-
venth Part of our Inch; but the Question
here was concerning a greater Alteration, per-
haps even twice as great, in a Rod of little
more than three Feet in Length.

Some Years after, Mess. *Deshayes, Varin,
Feuillée,* and *Couplet,* repeated the same Ex-
periment of the Pendulum near the Equator:
They found it necessary continually to shorten
it, the nearer they came to the Line, tho'
the Heats were often less under the Line it-
self,

self, than at fifteen or twenty Degrees distance.
This Experiment has been lately confirmed,
by the Academicians who are at present in
Peru; and they have just now informed us,
that about *Quito*, in a Time when it freezed,
they were obliged to shorten the Pendulum
for Seconds about two Lines, or the sixth
Part of a Digit.

While they were thus discovering of new
Truths, under the Line, Mr. *Picart*, in Con-
formity to the same Orders, gave to the
World in 1669 a Measure of the Earth, by
tracing over a small Part of the Meridian of
France. He did not indeed give so exact a
Measure of the Earth, as he might have
done, if he had measured the Degrees in
France both towards the Pole and towards the
Equator : But this Difference was too insigni-
ficant to be taken notice of, among the Things
that will now fall under our Consideration.

These Discoveries were necessary to found
the Theory of Sir *Isaac Newton*. We think
ourselves obliged here to insert a certain cu-
rious Anecdote, concerning these Discoveries
and this Theory, which will not be unpro-
fitable in the History of human Minds,

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and which will ferve to difcover the great
Neceffity of Exactitude in the Sciences, and
with what Sincerity Sir *Ifaac* proceeded in
his Search after Truth.

He had laid the Foundation of his admi-
rable Syftem of Gravitation ever fince the
Year 1666; but there was wanting, to re-
concile this Syftem with Truth in all its Parts,
and above all to draw thofe Conclufions from
the Motion of the Moon which we are by
and by to confider; there was wanting, I
fay, a Demonftration that the Degrees of
Latitude were every one about 25 common
French Leagues, that is, near 70 *Englifh*
Miles.

In the Year 1636, *Norwood*, an *Englifh*
Mathematician, had done that, in pure Cu-
riofity, which the Benevolence of the *French*
Minifter caufed *Picart* to undertake after-
wards, in 1669: He had made the fame Ex-
periments concerning the Degrees of Lati-
tude between *London* and *York*, in the North
of *England*, as *Picart* made to the North of
Paris, in a lefs Extent of Ground.

The Degrees of *Norwood* were found, with-
in a Trifle, to confift of 70 *Englifh* Miles,

or 25 *French* Leagues : This was precisely the Measure that Sir *Isaac Newton* had guess'd at by his Theory, and which alone could justify it.

But what will appear surprizing is, that in 1666, and even many Years after, Sir *Isaac Newton* knew nothing of *Norwood*'s Measures, taken above 30 Years before the Misfortunes which had afflicted *England*, had been as fatal to the Sciences as to the State : *Norwood*'s Discovery was buried in Oblivion ; every one kept to the erroneous Measure of the Pilots, who, in their random Computation, reckon'd only 60 Miles for a Degree of Latitude. And our Philosopher being retired into the Country during the Plague in 1666, was not in the Way of getting any Information concerning *Norwood*'s Measures, and therefore stuck to the false Computation of 60 Miles.

It was by this erroneous Measure that he proceeded to enquire, as we have already said, whether the same Power that occasions the Gravitation of Bodies towards the Center of the Earth, was what held the Moon in her Orbit. He found himself far enough from those Conclusions, which he could have drawn

O 4 with

with a more exact Measure of the Earth, and for that Time abandon'd his Research.

He resumed it some Years after, upon the Measures of *Picart*, and still farther confirmed himself in it in 1683, by the more exact Measures of *Cassini*, *Lattise*, *Chazelles*, and *Varin*, who, encouraged by *Colbert*, traversed a much larger Tract than *Picart*.

These Academicians examined the Meridian even as far as *Auvergne*; but *Colbert* being dead, *Louvois*, who succeeded him in the Jurisdiction of the Academy, but not in his Taste for the Sciences, interrupted a little this laborious Undertaking.

It was not till about that Time, that *Newton* became acquainted with the Operations of *Norwood*: He saw with Astonishment, that these Measures were the same with those of *Picart* and *Cassini*, with only this Difference, that *Norwood*'s Degree exceeded that of *Picart* 240 Fathoms, but surpassed that of *Cassini* only eight. *Newton* attributed this small Excess of 8 Fathom in a Degree to the Figure of the Earth, which he believed to be that of a Spheroid, depress'd or flatten'd towards the Poles; and he judg'd

that *Norwood*, by drawing his Meridian in Regions more Northerly than those of *France*, necessarily found his Degrees longer than those of *Cassini*, because he supposed that part measured by *Norwood* to have a longer Curve. However that be, here follows the sublime Theory which he drew from these Measures, and from the Discoveries of the great *Galileo*.

The Gravity of Bodies upon our Globe, is in reciprocal proportion of the Squares of their Distances from the Center of the Earth: Thus, the more these Distances are increased, the more is Gravity diminished.

Theory drawn from these Discoveries.

The Power which is the cause of Gravity, depends not upon Whirlpools of subtile Matter, the Existence of which is demonstrably false.

That Power, whatsoever it be, acts upon all Bodies, not according to their Surfaces, but in proportion to the Quantity of their Matter. If it acts at one Distance, it must act at all Distances: If it act in reciprocal Proportion of the Squares of these Distances, it must always act according to the same Proportion upon all known Bodies, when they

they are not at the Point of Contact, that is, let them be as near together as possible, without being joined.

If, according to this Proportion, the Power of Attraction, upon the Surface of our Globe, causes a Descent of 54,000 *Paris* Feet in 60 Seconds; a Body that shall be distant from the Center of the Earth about 60 of its Semi-diameters, by the same Rule will fall only fifteen *Paris* Feet in the same Time.

The same Power which occasions the Gravitation of Bodies towards the Earth, directs the Moon in its Course round the Earth.

The Moon, in her mean Motion, is distant about 60 Semi-diameters of our Terrestrial Globe, from the Center of that Globe. Now by the Measures taken in *France*, we know how many Feet the Moon's Orbit contains; we know that in her mean Motion, she describes 187,961 *Paris* Feet in a Minute.

The Moon, in her mean Motion, is advanced from A to B: She has obeyed then, both the projectile Force, which directs her in the Tangent A, C, and the Power which would make her descend according to the Line A, D, equal with B, C. Take away the Force which directs her from A to C,

and
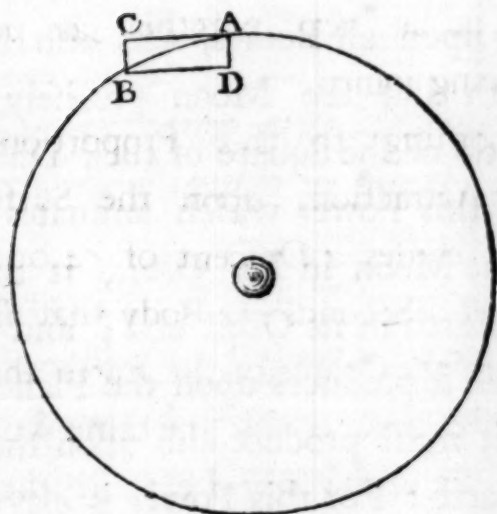
and there will remain a Force which may be estimated by the Line C, B. This Line C, B, is equal to the Line A, D: But it is demonstrable that the Curve A, B, being 187,961 Feet, the Line A, D, or C, B, will be only fifteen: Therefore whether the Moon falls into B, or into C, it is here the same Thing; she will have descended 15 Feet in a Minute from C to B; therefore she will have descended 15 Feet in a Minute also from A to D. But in descending this Space in a Minute, she will have travelled 3600 Times as far as a moveable Body upon the Earth would have travelled in the same Time: Now 3600 is just the Square of her Distance;

Diſtance; therefore the Gravitation which
acts here upon all Bodies, acts alſo between
the Earth and the Moon preciſely in the
ſame Ratio of the Square of their Diſtances.

But if this Power which animates Bodies,
directs the Moon in her Orbit, it muſt di-
rect the Earth in its Orbit alſo ; and the Ef-
fect which it produces upon the Planet of the
Moon, it muſt produce alſo upon the Planet
of the Earth : For this Power is every where
the ſame; all the other Planets muſt be ſub-
ject to it, and even the Sun alſo muſt expe-
rience its Law : And if there be no Motion
of the Planets with Regard one to another,
which is not the neceſſary Effect of this
Power, it muſt then be confeſſed, that all
Nature demonſtrates it : This is what we
proceed to obſerve, in a more ample Manner.

CHAP.

CHAP. XIX.

That Gravitation and Attraction direct all the Planets in their Courses.

ALMOST all the Theory of Gravity, according to *Descartes*, is founded upon this Law of Nature, that every Body which moves in a Curve Line, endeavours to move away from its Center in a right Line, which would touch the Curve in a Point. Such is the Sling, which escaping from the Hand at the Point B, would follow the Line B, C.

How we ought to understand the Theory of Gravity according to Descartes.
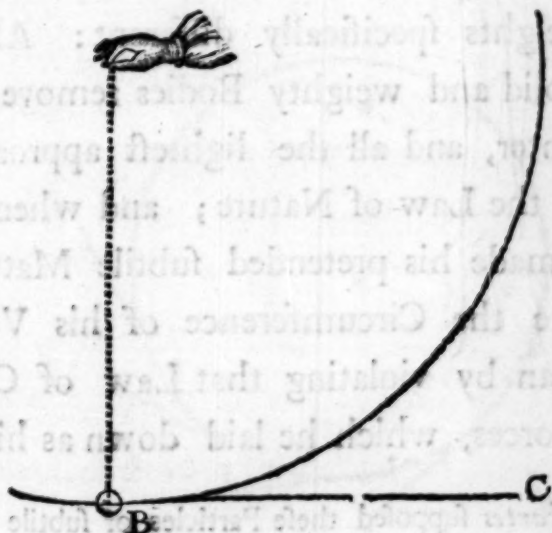
All Bodies, in turning with the Earth, endeavour thus to remove from the Center; but the fubtile Matter, fay they, making a much greater Effort, repells all other Bodies.

It is eafy to perceive, that it could not be in the fubtile Matter to make this greater Effort, and to remove itfelf from the Center of the pretended Vortex rather than other Bodies: On the contrary, it would be its Nature, (fuppofing it to exift) to make towards the Center of its Motion, and let the other Bodies, which are more compact and folid, move to the Circumference *. This is in Effect what happens upon a Table which is made to turn round, when in a Tube fixed thereon we put feveral Powers and Liquors, of Weights fpecifically different: All the moft folid and weighty Bodies remove from the Center, and all the lighteft approach it. Such is the Law of Nature; and when *Defcartes* made his pretended fubtile Matter to circulate the Circumference of his Vortex, he began by violating that Law of Centrifugal Forces, which he laid down as his firft

* *Defcartes* fuppofed thefe Particles of fubtile Matter to be moft hard and folid.

Principle.

Principle. It was to little purpose his imagining that God had created Dice * turning against one another; that the Rubbings of these Dice, which made his subtile Matter, dispersing on all sides, acquired thereby a swifter Motion; that the Center of a Vortex incrustated itself, &c. These Imaginations were far from rectifying his Error.

Without losing more Time to combat these imaginary Beings, let us follow the mechanical Laws which operate in Nature. A Body which moves circularly, at every Point of the Curve which it describes, takes a Direction that would remove it out of the Circle, by making it follow a right Line, in this **Manner.**

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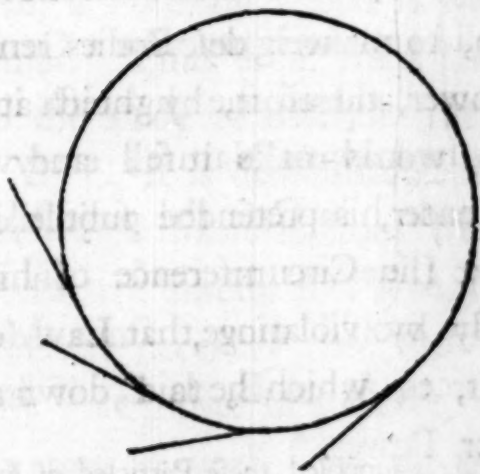
* He does not call them Dice but Particles of various Figures.
So

So far its true. But care muſt be taken that this Body do not thus remove from the Center, but by this other grand Principle: That every Body, being of itſelf indifferent with regard to Reſt and Motion, and having that *Vis inertiæ*, that Sluggiſhneſs which is an Attribute of Matter, follows neceſſarily the Line in which it is moved. Now every Body which turns round a Center, follows every Moment a right Line infinitely ſhort, which would become a right Line infinitely long, if it met with no Obſtacle. The Reſult of this Principle therefore, reduced to its juſt Value, is no more than this: That every Body which moves in a right Line, would always move in a right Line, if no Power acted upon it ; there is another Power wanting then, to make it deſcribe a Curve: This other Power, therefore, by which it deſcribes a Curve, would make it fall every Moment to the Center, in Caſe the projectile Motion in a right Line was to ceaſe. In a Word, this Body would move, from Moment to Moment, to A, to B, to C, if freed from the latter Power.

It would also, from Moment to Moment, fall from A, from B, from C, to the Center, if the other Power was wanting. The reason is, that its Motion is composed of two sorts of Motions, of a projectile Motion in a right Line, and also of an imprinted Motion in a right Line, by the Centripetal Force, a Force by which it would fall to the Center. Thus even from the Inclination of the Body to describe these Tangents A, B, C, it is demonstrable that there is a Power which draws it from these Tangents, even at the Instant that it begins them. It is absolutely necessary then, to consider every Body that moves in a Curve, as being moved by two Powers; one of which is, that which would make it describe Tangents, and

What is meant by the Centrifugal and Centripetal Forces.

P

and which is called the Centrifugal Power, or rather the Power of refting, of Inactivity, by which a Body always follows a right Line, if it meets with no Obftruction ; the other is the Power which draws the Body towards the Center, which is called the Centripetal, and is the true Power.

It is thus that a Body, moved according to the horizontal Line G, E, and according to the Perpendicular Line G, F, obeys thefe Powers every Moment, by paffing along the Diagonal G, H.
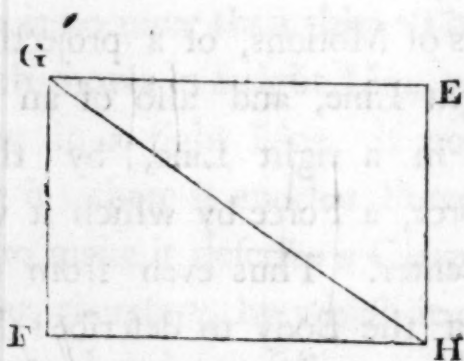
From the Eftablifhment of this Centripetal Force, there refults at firft Sight of this Demonftration : That every Body which moves in a Circle, or in an Ellipfis, or in any Curve whatfoever, moves round a Center to which it tends.

It follows moreover; that this Body, what Portions of the Curve foever it may pafs over, will always defcribe equal Areas in equal Times, both in its largeft and fmalleft Arches. If, for Inftance, a Body in one Minute defcribes the Space A, C, B, containing an hundred Miles of Area, it will in two Minutes defcribe the Space B, C, D, containing two hundred Miles.
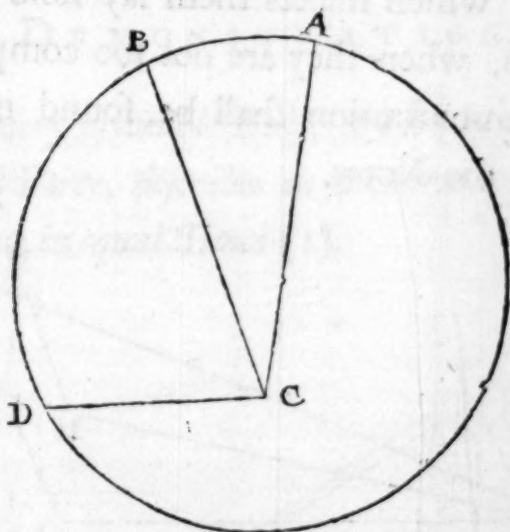
This Law inviolably obferved by all the Planets, and utterly unknown to Antiquity, was difcovered about 150 Years ago by *Kepler*, who has merited the Name of *Legiflator* in Aftronomy, notwithftanding his Philofophical Errors. He could not, however, come

at the Reafon of this Rule, to which all the Celeftial Bodies are fubject. The extreme Sagacity of *Kepler* difcovered the Effect, of which the Genius of *Newton* has found out the Caufe.

I fhall now give the Subftance of *Newton*'s Demonftration, which will eafily be comprehended by every attentive Reader: For Men have a natural Geometry in their Minds, which makes them lay hold of Proportions, when they are not too complicated. The Demonftration fhall be found more at large in the Notes.
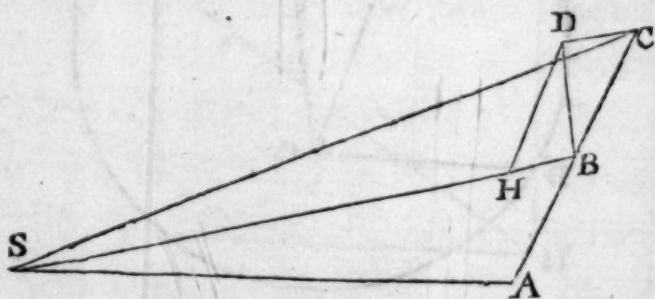
Let the Body A be moved to the Point B, in a very fhort Space of Time. At the End of an equal Space of Time, a Motion equally continued (for there is here no Acceleration) would bring it to the Point C: But in B it finds a Power which draws it in the Line B, H, S,

B, H, S. It does not follow then, either
the Road B, H, S, or the Road A, B, C:
Draw this Parallelogram C, D, B, H; and
then th⬛⬛⬛eing moved by the two Pow-
ers paffes along the Diagonal B, D. Now
this Line B, D, and this B, A, being fup-
pofed infinitely fhort, make a Curve, &c.
Therefore this Body neceffarily moves in a
Curve.

It

DEMONSTRATION.

That every moveable Body, drawn by a Centri-
petal Force, defcribes in a Curve Line, equal
Areas in equal Times (1).
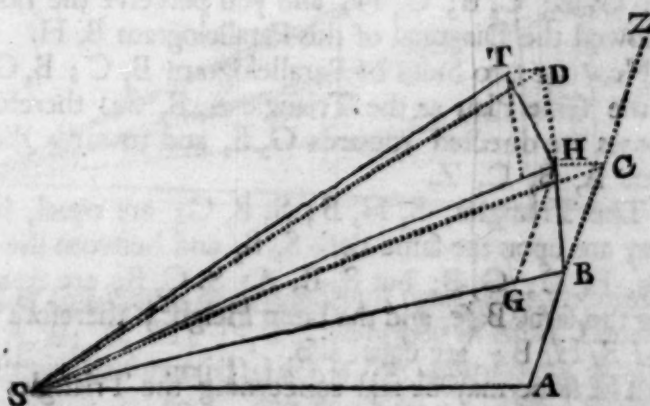
(1) All Bodies move in a uniform Motion, when there
is no accelerating Force: Therefore the Body A, moved
in a right Line in the firft Space of time from A to B, will

It muſt ſurround equal Spaces in equal Times; for the Space of the Triangle S, B, A, is equal to the Space of the Triangle S, B, H: Theſe Triangles are ⬛⬛⬛ therefore theſe Areas are equal; therefore every Body which ſurrounds equal Areas in equal Times, in a Curve, makes its Revolution round the Center of the Forces towards which it tends; therefore the Planets tend towards the Sun, turn round the Sun, and not the Sun round the Earth. For by taking the Earth

paſs in the ſame Time from C to Z. Theſe Spaces being conceived equal, the Centripetal Force in the ſecond Time gives a certain Motion, and the Body, inſtead of going to C, goes to H. Now what Direction has it had different from that of B to C? Draw the four Lines, C, H; G, B; C, B; G, H; and you perceive the Body has followed the Diagonal of this Parallelogram B, H.

Now the two Sides of Parallelogram B, C; B, G; are in the ſame Plan as the Triangle A, B, S; therefore the Forces are directed towards G, S, and towards the right Line A, B, C, Z.

The Triangles, S, H, B; S, B, C; are equal, becauſe they are upon the ſame Baſis S, B, and between the Parallels, H, C; G, B; but S, B, A; S, C, B; are equal, haing the ſame Baſe, and the ſame Height; therefore S, B, A; S, H, B; are equal alſo.

The ſame may be ſaid concerning the Triangles S, T, H; S, D, H; therefore all theſe Triangles are equal. Leſſen the Height to Infinity, the Body; in every Space of Time infinitely ſmall, will deſcribe the Curve, whoſe Lines all tend to the Point S; therefore in all theſe Inſtances, the Areas of theſe Triangles are proportional to the Times.

Earth for the Center, their Areas are found unequal in proportion to the Times; and in taking the Sun for the Center, these Areas are always found proportional to the Times; if you except only the small Irregularities, caused by the Gravitation of the Planets themselves.

The

DEMONSTRATION.

That every Body, describing in a Curve equal Triangles round a Point, is moved round that Point by a Centripetal Force (2).
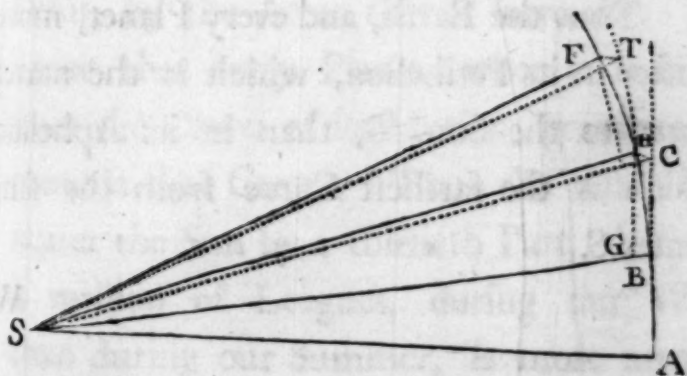
(2) Let this Curve be divided into equal Parts infinitely small, A, B; B, H; H, F; described in equal Times; let the Power be supposed to act at the same Points B, H, F; prolong A, B, to C, and B, H, to T; the Triangle S, A, B, will be equal to the Triangle S, B, H; for A, B, is equal to B, C; therefore S, B, H, is equal to S, B, C; therefore the Force in B, G, is parallel to that in C, H; but this Line B, G, parallel to C, H, is the Line B, G, S, tend-

ing

The better yet to underſtand what is meant by the Areas proportional to the Times, and to diſcover by Inſpection the Advantage you may draw from this Knowledge, conſider the Earth as carried in its Ellipſis round the Sun, S, its Center. When it goes from B to D, it encompaſſes as large a Space, as when it paſſes round the great Arch H, K: The Sector H, K, regains in Breadth what the Sector B, S, D, hath in Length. To make the Area of theſe Sectors equal in equal Times, the Body muſt paſs much ſwifter from H to K, than from B to D. Thus the Earth, and every Planet, moves ſwifter in its Perihelion, which is the neareſt Curve to the Sun, S, than in its Aphelion, which is the fartheſt Curve from the ſame Center S.

We

ing to the Center. The Body in H, is directed by the Centripetal Force along a parallel Line to F, T; in the ſame manner as in the Point B, it was directed by the ſame Force in a parallel Line to C, H: Therefore the Line parallel to F, T, will tend alſo towards S; therefore all Lines thus drawn, will tend to the Point S.

Conceive now to S, Triangles like thoſe above; the ſmaller thoſe Triangles above ſhall be, the more the Triangles to S, will approach to a phyſical Point, which Point S, will be the Center of the Forces.

We know then what is the Center of a Planet, and what Figure it defcribes in its Orbit, by the Areas that it furrounds: We know that every Planet, when it is farther from the Center of its Motion, gravitates lefs towards that Center. Thus the Earth being nearer the Sun by a thirtieth Part, that is by a million of Leagues, during our Winter than during our Summer, is more attracted alfo in Winter, and paffes fwifter then by reafon of its Curve: Thus we have eight Days and a half more Summer than Winter, and the Sun appears in the Northern Signs eight Days and a half more than in the Southern. Therefore fince every Planet fol-

It is for the preceding Reafons that we have more Summer than Winter.

lows,

lows, with regard to the Sun, its Center, that Law of Gravitation which the Moon experiences with regard to the Earth, and to which all Bodies are fubject in falling upon the Earth, it is demonftrable that this Gravitation, this Attraction, acts upon all Bodies that are known to us.

But another powerful Demonftration of this Truth, is the Law that all the Planets follows refpectively, in their Courfes, and in Diftances: This is what it is now incumbent on us to examine.

C H A P.

CHAP. XX.

Demonstration of the Laws of Gravitation, drawn from the Rules of Kepler: That one of these Laws of Kepler demonstrates the Motion of the Earth.

KEPLER found out another admirable Rule, of which I proceed to give an Example before I define it, in order to render the Thing more sensible and easy.

Kepler's Grand Rule.

Jupiter has 4 Satellites, which make their Revolutions round him: The nearest is distant 2 Diameters and five sixths, from Jupiter's Body, which it surrounds in 42 Hours: The most remote makes its Revolution in 402 Hours, I would know how far distant this last Satellite is from the Center of Jupiter. To accomplish this, I lay down the following Rule: As the Square of 42 Hours, the Revolution of the first Satellite, is to the Square of 402 Hours, the Revolution of the last; so is the Cube of 2 Diameters and $\frac{5}{6}$ to a fourth Term. This fourth Term being

found,

found, I extract its Cube Root, which Cube Root is found to be 12 ½: Thus I learn that the fourth Satellite is diftant from the Center of Jupiter 12 and ½ of his Diameters.

I make ufe of the fame Rule for all the Planets which revolve round the Sun, I fay; Venus revolves in 224 Days, and the Earth in 365: The Earth is 30 millions of Leagues from the Sun, how many Leagues then muft Venus be ? I anfwer ; as the Square of the Earth's Year is to the Square of the Year of Venus, fo the Cube of the Earth's mean Diftance is to a fourth Term, whofe Cubic Root will be about 21,700,000 Leagues, which make the mean Diftance of Venus from the Sun. I fay the fame with regard to the Earth and Saturn, &c.

This Law then is, that the Square of a Revolution of any one Planet, is always to the Square of the Revolutions of the other Planets, as the Cube of its Diftance is to the Cubes of the Diftances of the others, from the common Center.

Reafons unworthy of a Philo-fopher, gi-ven by Kepler for this admi-rable Rule.

Kepler, who found this Proportion, was very far from finding the Reafon of it. Being lefs a good Philofopher than an admirable A-
ftronomer,

ftronomer, he fays (in his 4th Book of his Epitome) that the Sun hath a Soul; not an intelligent Soul, *Animum*; but a vegetant, active Soul, *Animam:* That in turning round upon his own Axis, he draws the Planets to himfelf; but that the Planets do not fall on the Sun, becaufe they alfo revolve upon their Axis. In making this Revolution, fays he, they prefent to the Sun fometimes a friendly, and fometimes a hoftile fide; the friendly fide is drawn, and the hoftile fide is repell'd; which produces the annual Courfes of the Planets in the Ellipfes.

It muft be confeffed, for the Humiliation of Philofophy, that it was from this Reafoning, fo very unphilofophical, that he concluded the neceffity of the Sun's turning round on its Axis. Error accidentally conducted him to Truth; he conjectured the Rotation of the Sun on itfelf, above 15 Years before the Eyes of *Galileo* difcovered it by the Help of Telefcopes.

Kepler adds (in the fame Book, p. 495) that the Mafs of the Sun, the Mafs of all the Ether, and the Mafs of the Spheres of the fix'd Stars, are perfectly equal; and that they

they are the three Symbols of the Holy Trinity.

The Reader, who, in reading over thefe Elements, fhall have feen fuch extravagant Dreams, on the fide of fuch fublime Truths, in fo great a Man as *Kepler*, in fo profound a Mathematician as *Kircher*, ought not to be furprized at it : A Man may be a great Genius with regard to Calculations and Obfervations, and make a wrong ufe of his Reafon on other Accounts: There are Minds which have need of Geometry to fupport them, and which fall when they endeavour to proceed of themfelves. It is not furprifing therefore that *Kepler*, in difcovering thefe Aftronomical Laws, did not find out the Reafon of them.

The true Reafon of this Law found by Newton. This Reafon is, that the Centripetal Force is precifely in the reciprocal Proportion of the Square of the Diftance from the Center of Motion, towards which thefe Forces are directed : This is what we are to obferve attentively: In a Word, we ought throughly to underftand, that the Law of Gravitation is fuch, that every Body which approaches 3 Times nearer to the Center of its Motion,

I   gravi-

gravitates nine Times more ; that if it removes three times farther diftant, it will gravitate nine Times lefs ; and that if it removes to an hundred Times the Diftance, it will gravitate lefs 10,000 Times.

A Body moving circularly round a Center, gravitates then in the reciprocal Proportion of the Square of its actual Diftance from the Center, as alfo in direct Proportion of the Quantity of its Matter : It is demonftrable then, that it is Gravitation which occafions its Revolution round the Center, fince without this Gravitation it would remove from it, by defcribing a Tangent. This Gravitation therefore will be found to act moft ftrongly upon a Body which revolves with moft Velocity round the Center ; and the farther this Body fhall be removed, the more flowly will it turn, for then it will become the lefs ponderous.

It is for this Reafon that the Earth, tho' 1170 Times lefs than *Jupiter*, does neverthelefs weigh but 8 Times lefs than *Jupiter* upon the Body of the Sun; and this in direct Proportion of the Quantity of Matter in thefe Planets, and in reciprocal Proportion of the Squares of their Diftances from the Sun.

Thus

Thus have we demonſtrated this Law of Gravitation, in Proportion to the Squares of Diſtances;

1. By the Orbit which the Moon deſcribes, and by her Diſtance from the Earth, or Center.

2. By the Courſe of every Planet round the Sun in an Ellipſis.

3. By the Compariſon of the Diſtances and Revolutions of all the Planets round the common Center.

*Theſe Diſ-
coveries of
Newton
and* Kepler
*ſerve to
demon-
ſtrate that
it is the
Earth
which turns
round the
Sun.*

It will not be ſuperfluous to remark, that this ſame Rule of *Kepler*, which ſerves to confirm the Diſcovery of *Newton* concerning Gravitation, confirms alſo the Syſtem of *Copernicus* concerning the Motion of the Earth. It may be ſaid that *Kepler*, by this ſingle Rule, has demonſtrated what was diſcovered before him, and opened the Way to thoſe Truths which were to be diſcovered in after Times. For as on the one Side it is demonſtrable, that if the Law of centripetal Forces had no Place, *Kepler*'s Rule would be impoſſible: On the other it is demonſtrable, that according to the ſame Rule, if the Sun turned round the Earth, we ought to ſay; As the

Revo-

Revolution of the Moon round the Earth, is to the pretended annual Revolution of the Sun round the Earth so is the square Root of the Cube of the Moon's Distance from the Earth, to the square Root of the Cube of the Sun's Distance from the Earth. By this Calculation it would be found, that the Sun is only 510,000 Leagues from us; but it has been proved, that he is distant at least about 30 Millions of Leagues: Thus the Motion of the Earth then has been strictly demonstrated by *Kepler.* Here follows another very simple Demonstration, drawn from the same Reasons.

If the Earth was the Center of the Sun's Motion, as it is of the Moon's, the Sun's Revolution would take up 475 Years, instead of one Year: For the mean Distance of the Sun from the Earth, is to the mean Distance of the Moon from the Earth as 337 is to one: Now the Cube of the Moon's Distance is 1, the Cube of the Sun's Distance is 38272753: Finish the Rule, and say, As the Cube 1 is to this Cube Number 38272753; so the Square of 28, which is the periodical Revolution of the Moon, is to a fourth Number:

Demonstration of the Motion of the Earth, drawn from the same Laws.

You

You will find that the Sun would employ 475 Years, inftead of one Year, in making its Revolution round the Earth: Which demonftrates, that it is the Earth which turns.

It feems by fo much the more proper to Place thefe Demonftrations here, as there yet are Men deftined for the Inftruction of Youth, in *Italy*, in *Spain*, in *France*, and even in *England*, who doubt, or who affect to doubt, of the Earth's Motion.

It is proved then by *Kepler's* Law, and by that of *Newton*, that every Planet gravitates towards the Sun, the Center of the Orbits which they defcribe: Thefe Laws are fulfilled in the Satellites of Jupiter, with regard to Jupiter, their Center; in the Moons of Saturn, with regard to Saturn, and in our Moon, with regard to us: All thefe fecondary Planets, which roll round their central Planets, gravitate alfo with their central Planets towards the Sun: Thus the Moon, which is drawn round the Earth by the centripetal Force, is at the fame Time drawn by the Sun, round which fhe makes her Revolution. There is no Variety in the Moon's Courfe, in her Diftances from the Earth, in the Fi-

gure of her Orbit, fometimes approaching to an Ellipfis, fometimes to a Circle, &c. which is not from Gravitation, in proportion to her Diftance from the Earth, and her Diftance from the Sun.

If fhe does not always, in her Orbit, exactly defcribe equal Areas in equal Times, Sir *Ifaac Newton* has calculated all the Cafes where this Inequality muft happen: They all depend on the Attraction of the Sun, which draws thefe two Globes in direct Proportion of their Maffes, and in reciprocal Proportion of the Squares of their Diftances. We fhall fee, in the next Chapter, that the fmalleft Variation of the Moon, is a neceffary Effect of thefe united Powers.

Q 2   C H A P.

C H A P. XXI.

New Proofs of Attraction. That the Inequalities of the Motion and Orbit of the Moon are neceſſarily the Effects of Attraction.

THE Moon hath only one equal Motion, that of Rotation round herſelf on her own Axis; and this is her only Motion which we cannot perceive: It is this Motion that preſents us always, within a Trifle, with the ſame Diſc of the Moon; ſo that while ſhe really turns round upon herſelf, ſhe appears not to turn at all, and to have only a ſmall Motion of Balancing, of Libration, which ſhe has not, but which all Antiquity attributed to her.

All her other Motions round the Earth are unequal, and ought ſo to be, if the Rule of Gravitation be true. The Moon, in her Monthly Courſe, is neceſſarily nearer the Sun in one certain Point, and at one certain Time of her Courſe: Now in this Point, and at this Time, her Quantity of Matter remains

the same: Her Diftance only being changed, the Attraction of the Sun ought to change in reciprocal Proportion of the Square of this Diftance : The Courfe of the Moon ought then to change; fhe ought to move fwifter at certain Times, than the Attraction of the Earth alone occafions her to move : Now by the Attraction of the Earth fhe ought to pafs over equal Areas in equal Times, as you have already obferv'd in Chap. 19.

One cannot help admiring the Sagacity with which Sir *Ifaac Newton* has cleared up all thefe Inequalities, and regulated the Courfe of this Planet, which remained a Secret before, after all the Refearches of Aftronomers: It is upon this Account, above all, that we may fay:

Nec propius fas eft mortali attingere Divos.

Among the Examples that may be chofen, *Proof by* let us take this: Let A be the Moon; A, B, N, Q, *an Example.* the Orbit of the Moon ; S, the Sun ; B, the Place of the Moon in her laft Quarter.

She is now manifeftly at the fame Diftance from the Sun as the Earth. The Difference of the Obliquity of her Line of Direction to

the Sun being counted for nothing, the Gravitation of the Earth and of the Moon towards that Luminary is apparently the same. The Earth, however, advances in its annual Courſe from T to V, and the Moon in her Monthly Courſe advances to Z. Now in Z it is manifeſt that ſhe is more drawn by the Sun, S, to which ſhe finds herſelf nearer than the Earth : Her Motion then will be accelerated from Z towards N, and the Orbit that ſhe deſcribes will be changed : But how will it be changed ? In being flattened a little, in approaching more to a right Line from Z towards N. Thus, from Moment to Moment, Gravitation changes the Courſe and Form of the Ellipſis, in which this Planet moves.

By the ſame Reaſon the Moon ought to ſlacken her Courſe, and to change again the Figure of the Orbit that ſhe deſcribes, when ſhe returns from her Conjunction N, to her firſt Quarter Q ; for ſince from her laſt Quarter ſhe accelerated her Courſe, by flattening the Curve towards N, her Conjunction ; ſhe ought to ſlacken the ſame Courſe by ſwelling out the Curve, in returning from her Conjunction to her firſt Quarter.

But
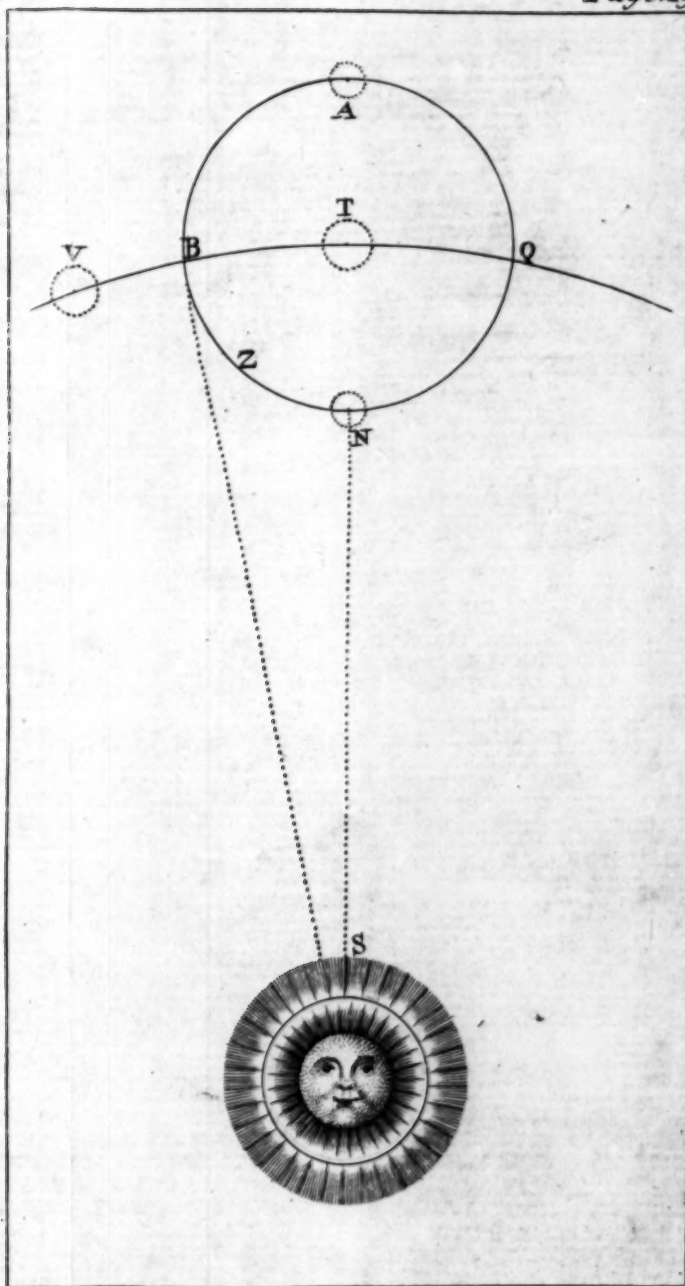
But when the Moon afcends from this firft Quarter towards her Full, A, fhe being then farther from the Sun, is lefs attracted by it, and gravitates more towards the Earth. Then the Moon accelerating her Motion, the Curve that fhe defcribes is again flattened a little, as in her Conjunction. And this is the only Reafon for which the Moon is farther from us in her Quarters, than in her Conjunction and Oppofition. The Curve that fhe defcribes is a kind of Oval, approaching to a Circle, almoft in this Manner.

The Earth

Thus the Sun then, to which fhe approaches, or from which fhe recedes at every Inftant, muft at every Inftant vary the Courfe of this Planet.

She hath alfo her Apogæon and her Perigæ-on, her greateft and her leaft Diftance from the Earth: But the Points, the Places of this Apo-gæon

The Inequalities of the Moon's Courfe all caufed by Attraction.

gæon and Perigæon, muſt neceſſarily change.

She hath her Nodes, that is to ſay, the Points where the Orbit ſhe deſcribes meets preciſely the Orbit of the Earth : But theſe Nodes, theſe Points of Interſection, muſt alſo continually vary.

She hath her Equator, inclined to the Equator of the Earth : But this Equator, ſometimes more and ſometimes leſs attracted, muſt likewiſe change its Inclination.

She follows the Earth notwithſtanding all theſe Varieties, and accompanies it in its annual Courſe : But the Earth, in this Courſe, is found to be a Million of Leagues nearer the Sun in Winter than in Summer. What is the Conſequence of this, independent of all theſe other Variations ? The Attraction of the Earth acts more fully upon the Moon in Summer, and then the Moon finiſhes her Monthly Courſe a little ſooner : But, on the contrary, in the Winter, the Earth itſelf being more attracted by the Sun, and moving with greater Velocity than in Summer, ſuffers the Motion of the Moon to diminiſh, and her Winter Months to be a ſmall Matter longer than her Summer ones. The little that

that we say of them, may suffice to give a general Idea of these Changes.

If any one should here start the Difficulty, which I have heard sometimes proposed, why the Moon, when she is most attracted by the Sun, does not fall upon that Luminary? We have only to consider for the present, that the Force of Gravitation, which directs the Moon round the Earth, is only diminished here by the Action of the Sun *: We shall see farther in the Article of Comets, why a Body which moves in an Ellipsis, and approaches its Center, nevertheless does not impinge upon this Center.

From these Irregularities of the Lunar *Deduction from these Truths.* Course, caused by Attraction, you will reasonably conclude, that no two Planets sufficiently near, sufficiently large to act upon one another sensibly, can at any Time move round the Sun in Circles, or even in Ellipses absolutely regular. Thus the Curves described by Jupiter and Saturn, for Example, are subject to sensible Variations, when these Pla-

* The Distance of the Moon from the Sun being vastly greater than from the Earth, she is attracted as much by the Earth as to overcome that of the Sun, and to balance the centrifugal Force.

nets are in Conjunction ; when, being the neareſt that poſſibly they can be to each other, and the fartheſt from the Sun, their mutual Action augments, and that of the Sun on them diminiſhes.

Gravita-
tion is not
the Effect
of the Pla-
nets
Courſes,
but their
Courſes are
the Effect
of Gravi-
tation.

This Gravitation then, augmented and leſſened in proportion to the Diſtances, neceſſarily aſſigns an irregular elliptical Figure for the Way of the greateſt Part of the Planets : Thus the Law of Gravitation is not the Effect of the Planetary Courſes, but the Orbits which the Planets deſcribe are the Effect of Gravitation. If this Gravitation was not, as it really is, in reciprocal Proportion of the Squares of Diſtances, the preſent Order of the Univerſe could not ſubſiſt.

If the Satellites of Jupiter and Saturn make their Revolution in Curves which approach nearer to a Circle, it is becauſe being very near the great Planets that are their Center, and very far from the Sun, the Action of the Sun cannot change the Courſe of theſe Satellites, as it changes that of our Moon. It is manifeſt then, that Gravitation, the Name of which alone ſeems ſuch a ſtrange Paradox, is a neceſſary Law in the Conſtitution of the

World :

World: So true, very often, is a thing that hardly has the Appearance of Probability!

Let us remember here, how abſurd the Opinion formerly ſeemed, that the Earth was not ſpherical; and yet it has been proved, that the Earth cannot have an entirely ſpherical Form : The like may be ſaid concerning Gravitation.

There is not at preſent any good Naturaliſt, who does not acknowledge both *Kepler*'s Rule, and the Neceſſity of admitting a Gravitation ſuch as *Newton* has proved : But there are yet ſome Philoſophers attached to their Vortices of ſubtile Matter, who would willingly reconcile theſe imaginary Vortices with theſe other demonſtrable Truths.

We have already ſeen, how far theſe Vortices are from being probable : But this Gravitation itſelf, does it not furniſh a freſh Demonſtration againſt them ? For ſuppoſing that theſe Vortices exiſted, they could not turn round a Center but by the very Laws of this Gravitation.   We muſt have recourſe to Gravitation, as the Cauſe of theſe Vortices, and not to the pretended Vortices as the Cauſe of Gravitation.

This Gravitation, this Attraction, may be a firſt Principle eſtabliſhed in Nature.

If

If at laft, being forced to abandon their imaginary Vortices, thefe Gentlemen are reduced to fay that this Gravitation, this Attraction, depends on fome other Caufe, or fome other fecret Property of Matter; either that Property will itfelf be the Effect of fome other Property unknown, or elfe it will be a primary Caufe, a firft Principle eftablifhed by the Author of Nature: Now why may not the Attraction of Matter itfelf be this firft Principle *?

* Some tell us that Matter being purely paffive cannot be an active Principle, elfe it might move itfelf as well as draw; we muft then fay it is fo, becaufe God would have it fo, and fo it's not an intrinfic effential Property: for the Sun repells the Light from it, and the Particles of Air one another in Rarefaction: Thus God the General in the Univerfe gives different Orders to different Bodies.

C H A P.

CHAP. XXII.

New Proofs and new Effects of Gravitation. That this Power is in every Particle of Matter. Discoveries dependent on this Principle.

WE may collect from all these Notions, that the Centripetal Force, Attraction, Gravitation, is the indubitable Principle of the Planetary Courses *, of the Descent of all Bodies, and of that Ponderosity which we experience in Bodies. This Centripetal Force, this Attraction, is not, nor can be, the simple Power of one Body to draw another to itself: We shall consider it here as a Power, from which results the Motion round a Center: This Power causes the Sun to gravitate towards the Center of the Planets, as the Planets gravitate towards the Sun, and draws the Earth towards the Moon, as well as the Moon towards the Earth.

One of the primitive Laws of Motion, is yet a fuller Demonstration of this Truth.

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* It is in Conjunction with the Projectile Force.

This

This Law is, that Re-action is equal to Action: Thus if the Sun gravitates on the Planets, the Planets gravitate on the Sun; and we shall see at the Beginning of the following Chapter, in what manner this great Law operates.

Now this Gravitation acting necessarily in direct proportion of the Quantity of Matter, and the Sun being about 760 Times as massy as all the Planets put together (without reckoning the Satellites of Jupiter, and the Ring and Moons of Saturn) it follows that the Sun must be their Center of Gravitation, and consequently, that they must revolve round that Luminary.

A general and important Remark concerning the Principle of Attraction. Let us carefully remark, that, when we say, the Power of Gravitation acts in direct Proportion of the Quantities of Matter, we always understand that this Power of Gravitation acts so much the more strongly on a Body, as this Body has a greater number of Particles; and we have demonstrated it, in shewing that a Straw descends as swiftly in the Machine purged of Air, as a Pound of Gold. We have said (making Allowance only for the small Resistance of the Air) that a leaden Ball, for Example,

ample,

ample, falls fifteen Feet in one Second upon the Surface of the Earth: We have demonstrated, that this same Ball would fall only fifteen Feet in a Minute, if it was removed from the Earth, as the Moon is, 60 of the Earth's Semidiameters: Therefore the Power of the Earth upon the Moon is to the Power that it would have upon a leaden Ball transported to the Elevation of the Moon, as the solid Body of the Moon would be to the solid Body of this Ball. It is in this Proportion that the Sun acts upon all the Planets; he draws Jupiter and Saturn, and the Satellites of Jupiter and Saturn, in direct proportion of the Quantity of solid Matter that is in each of these primary and secondary Orbs.

From hence flows an incontestible Truth; that this Gravitation is not only in the whole Mass of every Planet, but in every Particle of that Mass; and that thus there is not an Atom of Matter in the Universe, but what is invested with this Property.

From among the Methods in which *New-* *ton* has demonstrated that Gravitation is equally in every Atom, we will chuse here the most simple. If all the Parts of a Globe had

Gravitation, Attraction, is equally in all the Particles of Matter.

not equally this Property, if there were some weaker and some stronger Particles, a Planet, in turning upon its own Axis, would neceffarily present sometimes weaker and sometimes stronger sides at the same Diftance: Thus the same Bodies, on all possible Occasions, would experience at an equal Diftance, now one Degree of Gravitation, now another: The Law of reciprocal Proportion of the Squares of Diftances, and the Law of *Kepler*, would be always inverted, or proved not to subsist: Therefore there is not, in all the Planets, any one Particle of Matter that gravitates more than another.

Here follows another Demonstration of the same Truth. If there were Bodies in which this Property was different, some Bodies would fall more slowly, others more swiftly, in the empty Air-Pump. But all Bodies fall in the same Time; and all Pendulums of equal Length, whether of Gold, of Silver, of Iron, of Maple-wood, or of Glass, make equal Vibrations in the Air in equal Times: Therefore all Bodies have this Property of Gravitation precisely in the same Degree, that is, precisely in proportion to their

Mass,

Mass; so that Gravitation acts as a hundred upon a hundred Atoms, and as ten upon ten Atoms.

From Truth to Truth the human Mind rises insensibly to such sublime Points of Knowledge, as seem to be entirely out of its Sphere.

Sir *Isaac Newton* has ventured, by the help *A bold and admirable Calculation of Newton.* only of the Laws of Gravitation, to calculate what must be the Weight of Bodies in other Globes besides this which we inhabit; what the same Body, for Instance, which we here call a Pound, must weigh in the Moon, in Saturn, in the Sun: And as these different Weights depend directly on the Quantity of Matter in these Globes, it was necessary to calculate what that Quantity is. Let it not be said, after this, that Gravitation, that Attraction is an occult Quality: Let not any one dare to call by this Name an universal Law, which leads to such astonishing Discoveries!

There is nothing more easy than to know the Magnitude of any Celestial Orb, from the Moment that its Diameter is known: For the Product of the Circumference of the great Circle by the Diameter, gives the Surface of

the

the Globe; and the third of the Product of this Surface by the Semi-diameter, ſhews the Magnitude.

But by knowing the Magnitude, we learn nothing at all of the Quantity of Matter which this Orb contains. This too may be known, by that admirable Diſcovery of the Laws of Gravitation.

How to know the Quantity of Matter in a Globe, and what the ſame Bodies weigh upon diſtant Globes.

1ſt, *When the* Denſity, *or Quantity of Matter of any Globe is mentioned, we ſuppoſe that the Matter of this Globe is homogeneous; for Example, that every Cubic Foot of this Matter is equally weighty.*

2dly, *Every Globe attracts in direct proportion of the Quantity of its Maſs: Thus, all things equal, a Globe which ſhall have* 10 *Times more Matter, will attract, at the ſame Diſtance,* 10 *Times more ſtrongly than one of but a* 10th *Part of the Subſtance.*

3dly, *It is abſolutely neceſſary to conſider the Magnitude of the Circumference of the Globe under Examination: For the larger the Circumference, the more the Diſtance from the Center augments, and it attracts in reciprocal Ratio of the Square of this Diſtance. If the Diameter of the Planet A, for Inſtance, is four Times larger,*

2

larger than that of the Planet B, both having an equal Quantity of Matter; the Planet A, will attract Bodies to its Surface 16 Times less than the Planet B, and that which weighs a Pound upon the Planet A, will weigh 16 Pounds upon the Planet B.

4thly, It must be known, above all, in how long Time the Bodies attracted by the Globe, whose Density we enquire after, make their Revolution round this Globe: For, as we have seen in Chap. XIX. every Body circulating round another, gravitates the more, the more swiftly it turns: Now it must be for one of these two Reasons that it gravitates the more, either because it approaches nigher the Center which attracts it, or because this attracting Center contains more Matter. If I would know, therefore, the Density of the Sun, in comparison with the Density of the Earth, I must compare the Time of the Revolution of some Planet, as Venus, round the Sun, with the Course of the Moon round our Earth, and the Distance of Venus from the Sun, with the Distance of the Moon from the Earth.

5thly, I proceed thus. The Quantity of the Sun's Matter, in comparison with that of the

Earth,

Earth, is as the Cube of the Diſtance of Venus from the Center of the Sun to the Cube of the Moon's Diſtance from the Center of the Earth, (taking the Diſtance of Venus from the Sun to be 257 Times as great as that of the Moon from the Earth) and alſo in reciprocal Proportion of the Square of the periodical Revolution of Venus round the Sun, to the Square of the periodical Revolution of the Moon round the Earth.

This Operation being made, ſuppoſing always that the Sun is in Magnitude to the Earth as a Million to one, and counting ſtill in round Numbers, you will find that the Sun, a Million of Times larger than the Earth, contains only 250,000 Times as much Matter, or thereabouts.

This being ſuppoſed, I would know what Proportion is found between the Force of Gravitation on the Surface of the Sun, and that ſame Force on the Surface of the Earth; I would know, in a Word, how much that Body which weighs a Pound here, would weigh upon the Sun.

To come at this, I ſay; the Force of this Gravitation depends directly on the Denſity of

the attracting *Globes*, and on the *Distance* of the *Center* of these *Globes* from the ponderous *Bodies* on their *Surface*. Now the *Distance* between the *Bodies* and the *Center*, is precisely the *Semi-diameter* of the *Globes* : But the *Semi-diameter* of the *Globe* of the *Earth* is to that of the *Sun* as 1 to 100, and the respective *Density* of the *Earth* is to that of the *Sun* as 4 to 1: Then *I* say ; as 100, the *Semi-diameter* of the *Sun*, multiplied by 1, is to 4, the *Density* of the *Earth*, multiplied by 1; so is the *Weight* of *Bodies* upon the *Surface* of the *Sun* to the *Weight* of the same *Bodies* upon the *Surface* of the *Earth*. This proportion between 100 and 4, being reduced to other *Terms*, is as 25 to 1 : A *Pound*, therefore, weighs 25 *Pounds* upon the *Surface* of the *Sun* ; which answers my *Question*.

I have supposed here the respective *Densities* of the *Earth* and *Sun* to be as 4 to 1 ; but this is not the exact *Proportion* : The *Weight* of *Bodies*, therefore, upon the *Surface* of the *Sun*, is to that of *Bodies* upon the *Earth*, not as 25, but as 24 to 1.

We cannot have the same *Notions* concerning all the *Planets* ; for those which have

no Moons, no Satellites, being deſtitute of Orbs of Compariſon, cannot be ſubject to our Reſearches : Thus we know not the Proportion of Gravity, that ſubſiſts between Mercury, Mars, Venus, and us, but we know that of the other Planets.

I proceed to give a ſhort Theory of all our Planetary World, ſuch as the Diſcoveries of Sir *Iſaac Newton* make it appear to us. Thoſe who would become Maſters of the more profound Reaſon of theſe Calculations, may read Sir *Iſaac* himſelf, or Mr. *Gregory*, or Mr. *Graveſande*. The Reader need only be informed, that in following the Proportions diſcovered by *Newton*, we have kept to the Aſtronomical Calculation of the *Paris* Obſervatory. Whatever the Calculation may be, the Proportions and Proofs are the ſame.

CHAP.

CHAP. XXIII.

The Theory of our Planetary World.
The SUN.

THE Sun is the Center of our Planetary World, and ought necessarily to be there. We do not mean by this, that the middle Point of the Sun is precisely the Center of the Universe; but that the central Point towards which our Universe gravitates, is necessarily in the Body of that Luminary, and all the Planets, having once received their projectile Motion, must continually turn round this Point, which is in the Sun. We prove it thus.

Let the greatest of these two Globes, A, and B, represent the Sun, and the least any Planet whatsoever. If they are both abandoned to the Law of Gravitation, and free from all other Motion, they will be attracted in direct Proportion of their Quantity of Matter; they will be determined towards one another in a straight Line; and A, being a Million of Times larger than B, will force B to move towards it a Million of Times faster than A will move towards B.

But

Demon-ftration of the Earth's Motion round the Sun, drawn from the Law of Gravita-tion.

But let them both have a projectile Motion, in proportion to their Maffes *, the Planet in the Line B, C, the Sun in the Line A, D, and then the Planet is under two Forces; it tends in the Line B, C, and gravitates at the fame time towards the Sun in the Line A, B: It will therefore defcribe the Curve B, F; and the Sun, in like manner, will follow the Line A, E; and both, gravitating towards each other, will turn round a common Center; But the Sun furpaffing the Earth in Magnitude a Million of Times, and the Curve A, E, which he will defcribe, being a Million of Times lefs than that which the Earth defcribes, this common Center is neceffarily near the Middle of the Sun.

* The Sun can have no projectile Force, not from the Earth; for the Earth hath it not from the Sun, but from an intelligent Being.

It

It is hereby again demonstrated, that the Earth and the Planets turn round this Luminary: And this Demonstration is by so much the more beautiful and strong, as it is entirely independent on Observation, and founded upon the primordial Mechanism of the World.

If we make the Diameter of the Sun equal *The Sun's Magnitude.* to 100 Diameters of the Earth, and if consequently, the Sun surpasses the Earth a Million of Times in Magnitude; it will follow, he is 760 times larger than all the Planets together, leaving out the Satellites of Jupiter and Saturn's Ring. He gravitates towards the Planets, and the Planets too gravitate towards him; it is this Gravitation that makes them circulate, by drawing them from a Tangent*; and the Attraction which the Sun exercises upon them, surpasses that which they exercise upon him, as much as he surpasses them in Quantity of Matter. Never lose Sight of this Truth, that reciprocal Attraction is nothing but the Law of moveable Bodies, all gravitating, and all turning round one common Center.

* Nothing determines the Sun to move in a Tangent.

The

The Sun then turns round this common Center, that is, upon his own Axis, in 25 Days and ½. His middle Point is always a little diſtant from this common Center of Gravity, and his Body removes from it in proportion as ſeveral Planets in Conjunction attract him towards them : But if all the Planets were on one Side, and the Sun on the other, the common Center of Gravity would hardly be out of the Sun's Body; their united Forces being ſcarcely ſufficient to diſorder and remove the Sun one entire Diameter.

He really changes Place then every Moment, according as he is more or leſs attracted by the Planets ; and this little Approach of the Sun re-eſtabliſhes that Diſorder which the Planets operate on one another : Thus the continual Irregularity of this Luminary preſerves the Order of Nature.

Tho' he ſurpaſſes the Earth in Magnitude a Million of Times, he contains not a Million of Times as much Matter, as was before ſaid.

If he was actually a Million of Times more ſolid, more compact than the Earth, the Order of the World would not be what it now

is :

is: For the Revolutions of the Planets, and their Diftances from their Center, depend on their Gravitation, and their Gravity is in di-rect Proportion of the Quantity of Matter in the Globe which is their Center : Therefore if the Sun furpaffed our Earth and our Moon in folid Matter to fuch a great Excefs, the Planets would be much more attracted, and their Ellipfes much lefs regular, than they are at prefent.

In the fecond Place, the Matter of the Sun cannot be in proportion to his Magnitude ; for his Globe being all on fire, its Rarefac-tion is neceffarily very great, and the Matter is lefs in proportion as the Rarefaction is greater. *His Den-fity.*

By the Laws of Gravitation it appears, that the Sun contains but 250,000 Times as much Matter as the Earth : Now the Sun, a Mil-lion of Times larger, being but the fourth Part of a Million more material than the Earth; the Earth, a Million of Times lefs, has in Proportion four Times as much Mat-ter as the Sun, and is four Times as denfe.

The fame Body, according to this Com-putation, which weighs a Pound upon the
Sur-

Surface of the Earth, would weigh 25 Pounds upon the Surface of the Sun : But the true Proportion is only of 24 to 1, becaufe the Earth is not in Effect four Times as denfe as the Sun, and becaufe the Diameter of the Sun furpaffes that of the Earth only 95 Times and an half.

In what Proportion Bodies defcend upon the Sun.

The fame Body which defcends here 15 Feet in the firft fecond, would defcend about 350 Feet upon the Surface of the Sun, all other things being equal.

The Sun lofes daily, according to Sir *Ifaac*, a little of his Subftance, and would be in the Revolution of many Ages reduced to nothing, if the Comets, which from Time to Time impinge on his Sphere, did not ferve to repair his Loffes ; for every thing in the Univerfe alters, and is repaired.

MERCURY.

From the Sun to the Diftance of eleven or twelve Millions of *French* Leagues, or thereabouts, there does not appear any Globe.

At 11 or 12 Millions of Leagues from the Sun is Mercury, in his mean Diftance. This is the moft excentric of all the Planets ; he

turns

turns in an Ellipsis, which puts him in his Perihelion near *almost a third part* a third Time nearer the Sun than in his Aphelion : Such is, within a Trifle, the Curve that he defcribes.

Mercury is almoft 27 Times lefs than the Earth : He turns round the Sun in 88 Days, which conftitute his Year.

His Revolution upon his own Axis, which makes his Day, is unknown ; nor can either his Weight, or his Denfity, be afcertained. We only know, that if Mercury be an Earth exactly like ours, the Matter of its Globe muft be about 8 Times more denfe than ours : Otherwife, every thing there would be in fuch a Degree of Effervefcence, as would deftroy Animals of our Species in an Inftant, and cause

Newton's Idea concerning the Denfity of Mercury.

cause all Matter of the Confiftence of the Waters on our Globe to evaporate.

Here follows a Proof of this Affertion. Mercury receives about 7 Times more Light than we, in Proportion to the Square of Diftances, becaufe it is about $2\frac{2}{3}$ Times nearer the Center of Light and Heat; it is therefore 7 Times more fuffocated, all things being equal. Now upon our Earth the great Heat of Summer being augmented 7 or 8 Times, makes the Water boil up immediately in large Bubbles: Therefore it is neceffary that every thing fhould be about 7 Times more denfe than it is, to refift 7 or 8 Times as much Heat as the moft fcorching Summer produces in our Climates: Therefore Mercury ought to be at leaft 7 Times more denfe than our Earth, to make it poffible for the fame Things as fubfift in our Earth to fubfift in the Globe of Mercury, all things being equal. Finally, if Mercury receives about 7 Times more Rays than our Globe, becaufe it is about $2\frac{2}{3}$ Times nearer the Sun; by Parity of Reafon, the Sun appears in Mercury 7 Times larger than on our Earth.

VENUS.

VENUS.

After Mercury is Venus, at between 21 and 22 Millions of Leagues from the Sun in its mean Diſtance: It is as large as the Earth, and its Year conſiſts of 224 Days. We do not yet know the Length of its Day, that is, of its Revolution on its own Axis. Very great Aſtronomers believe this Day to be only 23 Hours; others lengthen it to 25 of our Days. There have not hitherto been made any Obſervations, ſufficiently certain to ſhew on which Side is the Error: But this Error, wherever it be, can be only a Miſtake of the Eyes, an Error of Obſervation, and not of Judgment.

The Ellipſis which Venus deſcribes in its Year, is leſs eccentric than that of Mercury: One may form to himſelf ſome Idea of the Way of theſe two Planets round the Sun, from the ſubſequent Figure.

It
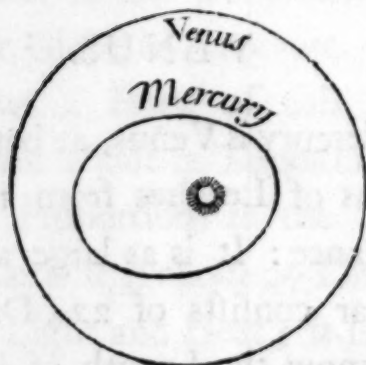
Prediction of Copernicus concerning the Phases of Venus.

It is not foreign to our Purpose to remark here, that Venus and Mercury have different Phases with regard to us, as well as the Moon. *Copernicus* was formerly reproached, for that these Phases ought to appear in his System; which it was concluded was false, because no such Phases could be perceived. If Venus and Mercury, said his Antagonists, turn round the Sun, and we turn in a greater Circle, we ought to see Venus and Mercury, sometimes full, sometimes increasing, &c. but this is what we have never seen. It is nevertheless what really happens, answered *Copernicus*, and what you will see hereafter, if ever you find Means to make your Sight more perfect. The Invention of Telescopes, and the Observations of *Galileo*, conspired soon after to accomplish the Prediction of *Copernicus.*

pernicus. As to other Particulars, nothing certain can be said concerning the Quantity of Matter in Venus, or the Ponderosity of Bodies on this Planet.

The EARTH.

Next after Venus is placed the Earth, at 30 Millions of Leagues from the Sun, or thereabouts, at least in its mean Distance.

It is near a million of Times less than the Sun, towards which it gravitates, and round which it revolves in an Ellipsis in 365 Days, 5 Hours, and 48 Minutes; travelling at least 180 Millions of Leagues every Year. The Ellipsis which it describes is very irregular, on Account of the Moon's Action upon it; so that while the common Center of the Earth and the Moon describes a true Ellipsis, the Earth actually describes the following Curve every Lunar Revolution.

The insensible Curve which the Earth describes each Lunation.

S

The
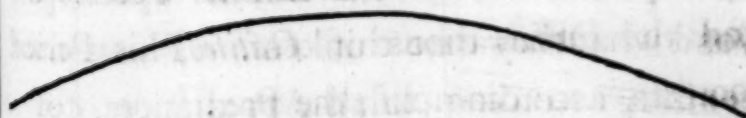
The Earth's Rotation upon its own Axis from Weft to Eaft conftitutes its Day of 23 Hours, 56 Minutes. This Motion is not the Effect of Gravitation. It feems impoffible here, in particular, to have Recourfe to that fufficient Reafon fpoken of by that great Philofopher *Leibnitz*. It is abfolutely neceffary to confefs, that the Planets and the Sun might as well turn from Eaft to Weft: Therefore we muft allow, that this Rotation from Weft to Eaft is an Effect of the Free-will of the Creator, and that this Free-will is the only fufficient Reafon that can be affigned for it.

The Earth has another Motion, which is finifhed by its Poles in 25,920 Years. Its Gravitation towards the Sun and the Moon is evidently the Caufe of this Motion, as we fhall prove in the 25th Chapter.

The Earth has yet another Revolution, much more ftrange, the Caufe of which is unknown, the Length of which aftonifhes the Imagination; and feems to promife a Duration to the human Species beyond what they dare think of. This Period confifts, according to all Appearances, of a million,

million, nine hundred and forty four thou-
sand Years. It is here that we must insert
what is known of this surprising Discovery,
before we finish the Article of the Earth.

A Digression.

Concerning the Period of 1,944,000 *Years,*
newly discovered.

Egypt and Part of *Asia,* from whence all
the Sciences that now seem to circulate in the
World devolv'd to us, preserved antiently an
immemorial, extravagant, uncertain Tradition,
but which could not be without some Foun-
dation. They said, that prodigious Changes
had been made in our Globe, and in the
Heavens with regard to our Globe. The
bare Inspection of the Earth gives great
Weight to this Opinion.

We see that the Waters have successively
covered and abandoned the Beds which con-
tain them. The Vegetables and Fishes of
India, found in the Petrifications of our *Eu-*
rope, the Numbers of Shells found in Ranges
in the Mountains, render sufficient Testi-
mony to this antient Truth.

S 2 *Ovid,*

Ovid, explaining the Philofophy of *Py-thagoras*, and introducing a Difcourfe of that Pupil of the *Afian* Sages, fpeaks in the Name of all the Oriental Philofophers, when he fays:

Nil equidem durare diu fub imagine eâdem
Crediderim ; fic ad ferrum veniftis ab auro
Secula, fic toties verfa eft fortuna locorum.
Vidi ego quod fuerat quondam folidiffima tellus
Effe fretum : vidi faƈtas ex æquore terras :
Et procul à pelago conchæ jacuere marinæ :
Et vetus inventa eft in montibus anchora
*   fummis.*
Quodque fuit campus, vallem decurfus aquarum
Fecit ; & eluvie mons eft deduƈtus in æquor,
Eque paludofa ficcis humus aret arenis.

Which Verfes are thus tranflated by Mr. *Dry-den*:

That Forms are chang'd I grant ; that no-
    thing can
Continue in the Figure it began :
The golden Age to Silver was debas'd ;
To Copper that ; our Metal came the laft.
The Face of Places, and their Forms, decay ;
And what was folid Earth, converts to Sea :
Seas in their turn retreating from the Shore,
Make folid Land, what Ocean was before :
                                        And

And far from Strands are Shells of Fishes
   found ;
And rusty Anchors fix'd on Mountain
   Ground :
And what were Fields before, now wash'd
   and worn,
By falling Floods from high, to Vallies turn,
And crumbling still descend to level Lands ;
And Lakes, and trembling Bogs, are barren
   Sands :
And the parch'd Desart floats in Streams
   unknown ;
Wond'ring to drink of Waters not her own.

This was the Opinion of the East ; and we
do it no Injury by reporting it in Verse, the
antient Language of Philosophy.

To these Testimonies which Nature gives,
of so many Revolutions which have changed
the Face of the Earth, corresponds an Idea
of the antient *Egyptians,* a People formerly
skill'd in Geometry and Astronomy, before
Superstition and Sloth had reduced them to
Contempt. This Idea was, that the Sun, in
former Ages, rose in the West. It was a
Tradition, indeed, as obscure as their Hiero-
glyphicks. *Herodotus,* who may be looked

upon

upon as an Author too modern, and confe-
quently of little Weight with regard to fuch
Antiquities, reports in his Book *Euterpe*, that,
according to the *Egyptian* Priefts, the Sun,
in the Space of eleven thoufand three hun-
dred and forty Years (and the *Egyptian* Year
confifted of 365 Days) had rifen twice where
he now fets, and fet where he rifes, without
there being the leaft Change in *Egypt*, occa-
fioned by this Variation of the Solar Courfe.

Either the Priefts, who related this Event
to *Herodotus*, explained themfelves imperfect-
ly, or *Herodotus* mifunderftood them. For it
might be a probable Tradition among Philo-
fophers, that the Sun had changed his Courfe;
but that the Cardinal Points fhould be twice
changed in eleven thoufand and odd Years,
was a thing impoffible. Thefe two Revolu-
tions, as we are going to make it appear,
could not happen in much lefs than 4 Mil-
lions of Years. The entire Revolution of the
Poles of the Ecliptic, or the Equator, is fi-
nifhed in about 1,944,000 Years; and this
Revolution of the Ecliptic and the Equator
alone, by the Help of the diurnal Motion of
the Earth, is fufficient to turn our Globe
fuc-

succeſſively to the Eaſt, to the South, to the Weſt, to the North. Thus it is in a Period of no leſs than 1,944,000 Years, that our Globe could twice ſee the Sun riſe in the Weſt, and not in 110 Centuries only, according to the wild Report of the *Theban* Prieſts, and of *Herodotus*, the Father of Hiſtory and Falſhood.

Beſides, it is impoſſible that this Change could happen, and *Egypt* not be affected by it: For if the Earth, in turning daily on itſelf, had ſucceſſively finiſhed its Year from Weſt to Eaſt, from North to South, from Eaſt to Weſt, and from South to North, by raiſing itſelf on its Axis; it may be clearly perceived, that the Poſition of *Egypt*, and of all the Climates of the Earth, muſt have been changed. The Rains, which have ſo long continued to fall from the Tropick of Capricorn, and which fertilize *Egypt* by ſwelling the *Nile*, would have ceaſed. The Place of *Egypt* would have been removed into a frozen Zone, and both *Egypt* and the *Nile* would have diſappeared.

Plato, *Diogenes*, *Laertius*, and *Plutarch*, ſpeak not more intelligibly of this Revolu-

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tion. Speak of it however they do, and are
so many remaining Witnesses of a Tradition
almost lost.

What follows is much more shocking, and
more circumstantial. The Philosophers of
Babylon, at the Time of *Alexander*'s Entry
into that City, counted four hundred and
three thousand Years from the beginning of
their astronomical Observations, the *Babylo-
nian* Year being but 360 Days: But this Epo-
cha of 403,000 Years has been regarded as a
Monument of the Vanity of a conquered Na-
tion, which was willing, according to the
Custom of all Nations, and all particular Per-
sons, to recover by its Antiquity the Glory
that it had lost by its Weakness.

The Sciences, at last, having been brought
among us, and being cultivated by Degrees,
the Chevalier *de Louville*, distinguished among
the Croud of them who did Honour to the
Age of *Louis* XIV. went expresly to *Mar-
seilles*, to see if the Obliquity of the Ecliptic
appear'd the same there as it had been ob-
served and fixed by *Pitheas*, above 2000 Years
ago. He found this Obliquity of the Eclip-
tic, that is, the Angle formed by the Axis

of the Equator, and the Axis of the Ecliptic, to be 20 Minutes lefs than *Pitheas* had found it.   How did this 20 Minutes Diminution of this Angle agree with the Opinion of antient *Egypt*, and with the 403,000 Years of which *Babylon* boafted ?   How, with a Period of the World of near 2 Millions of Years, and even, according to *Louville*'s Obfervation, of above 2 Millions ?   We muft fee the Ufe he made of it, and how there is like to refult from it, hereafter, an Aftronomy altogether new.

If the Angle which the Axis of the Equator makes with the Axis of the Ecliptic be 20 Minutes lefs at this Day than it was 2000 Years ago, the Axis of the Earth, by rifing upon the Plan of the Ecliptic, comes nearer it a whole Degree in 6000 Years.

Let this Angle, P, E, for Example, be about $23\frac{1}{2}$ Degrees at this Day, and let it continue to decreafe till it becomes nothing; then let it begin again to increafe and decreafe, it will certainly happen, that in $23\frac{1}{2}$ Times 6000 Years, that is, in 141,000 Years, our Ecliptic and our Equator will coincide in all their Points; the Sun will be in the

Equator,

Equator, or at leaft will remove little from it, during many Centuries; the Days, the Nights, the Seafons, will be equal all over the Earth. It is found, according to the Calculation of the *French* Aftronomer, a Calculation a little reformed fince, that the Axis of the Ecliptic was perpendicular to that of the Equator about 399,000 of our Years ago, fuppofing the World to have exifted fo long. Take from this Number, the Time that is elapfed fince *Alexander*'s triumphant Entry into *Babylon*, and we fhall fee with Aftonifhment that this Calculation agrees very juftly with the 403,000 Years of 360 Days, which were computed by the *Babylonians*: We fhall fee that they begun this Computation precifely at the Point where the Pole of the Earth was directed towards Aries, and when the Earth in its annual Courfe had revolved from South to North ; in a Word, when the Sun rofe and fat in the Regions of Heaven which now are the Poles.

There is fome Appearance that the *Chaldæan* Aftronomers had made the fame Operation, and confequently the fame Deduction from it, as the *French* Philofopher ? They had

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had measured the Obliquity of the Ecliptic,
and found it decreasing ; and rising in their
Calculations to a Cardinal Point, counted from
that Point when the Ecliptic and the Equa-
tor made an Angle of 90 Degrees ; a Point,
which may be considered as the Beginning,
as the End, as the Half, or as the Quarter
of this enormous Period.

By this the Enigma of the *Egyptians* was
unravelled, the Computation of the *Chaldeans*
justified, the Relation of *Herodotus* clear'd
up, and the Universe flattered with a long
Futurity, the Idea of which pleases the hu-
man Imagination; tho' this Comparison makes
our Life appear yet the shorter.

This Discovery of the Chevalier *de Louville*
was strongly opposed, both because it was
very strange, and because it did not yet seem
sufficiently confirmed.   An Academician had,
in a Voyage to *Egypt*, measured a Pyramid :
He found its four Sides opposed to the four
Cardinal Points; therefore the Meridian, said
the Enemies of the Chevalier, has not changed
during so many Centuries ; therefore the
Obliquity of the Ecliptic, which by its Di-
minution must have changed all the Meri-
dians,

dians, in reality has not been diminiſhed. But this Pyramid was no impregnable Barrier againſt theſe new Diſcoveries: For, how are we ſure that the Architects of the Pyramid were not ſome Minutes deceived? The moſt inſenſible Aberration, in laying a Stone, had alone been ſufficient to occaſion this Error. Or, if the Builders were right, might not the Academician himſelf neglect that little Diverſity, which might be found between the Points where the Sun ought to mark the Equinoxes and Solſtices upon this Pyramid, ſuppoſing nothing to have changed, and the Points where it now marks them in Fact? Could not he be deceived in the Fables of *Egypt*, where he operated out of pure Curioſity, when *Tycho-Brahe* himſelf was deceived 18 Minutes in the Poſition of the Meridian of *Uraniburg*, his heavenly City, for which he calculated all his Obſervations? Or was *Tycho-Brahe* in reality deceived 18 Minutes, as is pretended? May not the Truth be, after all, that this Difference found between the true Meridian of *Uraniburg*, and that of *Tycho-Brahe*, proceeds partly from the Change of Heaven itſelf, and partly from the almoſt

inevitable

inevitable Errors committed both by *Tycho-Brahe* and by them that corrected him?

But the Chevalier *de Louville* might also be deceived himself; he might see a Decrease of Obliquity, which has no Existence. *Pitheas*, especially, was probably the Source of all these Errors: He, like most of the Antients, made his Observations with very little Exactness. It was worthy of that Prudence therefore, with which we now proceed in Physicks, to wait for new Illustrations of the Matter. Therefore it was proper that the few, who were able to judge of this grand Difference, should remain in Silence for the present.

Finally, in 1734, Mr. *Godin* (one of those Philosophers whom the Love of Truth has lately conducted to *Peru)* resumed the Thread of these Discoveries: The Examination of a Pyramid was now no more the Matter in Question, for concerning this there would be Difficulties always remaining; he was to proceed from the famous Meridian in the Church of St. *Petronius*, traced by *Dominic Cassini* in 1655, with an Exactness of which we are more certain than that of the *Egyptian* Architects,

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The Obliquity of the Ecliptic which refulted
from *Caffini*'s Obfervation, was 23 D. 29′.
15″. But the late Obfervations put it beyond
all Doubt, that this Angle of the Ecliptic
and the Equator is at prefent 23 D. 28′. 20″,
at leaft if the Refractions, which enter into
the Determination of the Height of the Pole,
made by the Polar Heat, and confequently
into that of the Elevation of the Equator, and
the Obliquities of the Ecliptic, are not a lit-
tle changed fince *Caffini*'s Time : A Variation
which many begin to fufpect, from the Diffe-
rence of the Elevations of the Pole, obferved
in the fame Cities after fome Space of Time,
particularly in *London*, *Amfterdam*, and *Copen-
hagen*; tho' thefe Obfervations are not yet
fufficient to affure us entirely, that from Age
to Age the Air is found fometimes more, fome-
times lefs tranfparent. It has indeed been
lately difcovered, and infallibly demonftrated,
that the Refractions at two Places, a very
little diftant, will fometimes differ almoft be-
yond Belief; which obliges an exact Obferver,
at prefent, to determine well, before every
Thing elfe, the Refractions of his Horizon,
if he would have his Obfervations credited:
But

But it is also known, that, according to the Experiment of Mr. *Huygens,* if a reflecting Glass be left in a constant Situation, directed towards the Top of a high Steeple, from Noon till Evening, that Top will appear more elevated towards the Close of Day than at Noon, and consequently there is an Alteration in the Transparency of the Air. As all this, however, contributes nothing to a Change, such as we have reason to suspect may produce the Phænomenon of this Question, we should be blameable to admit such a dubious Fact, of which we have not yet any convincing Proof, any Physical Reasons.

With regard to the Pyramids of *Egypt,* and the Invariableness of Meridians, which seems contrary to this Mobility of the Poles of the Equator; it is proper to take Notice farther, That supposing the Figure of the Earth to be not spheroidical, as it really is, but exactly spherical, this Motion of the Plan of the Equator, and its Poles, may be conceived two ways. For, either most of the Places, situated at present under the Equator, will, after some Ages, have a Meridional or Septentrional Latitude, the Equator

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tor having quitted them to come nearer the
Ecliptic ; (on which Suppofition, all the Me-
ridians will be difordered, and any two Cities,
without having changed their Place, their Di-
ftance, or their firft Situation upon Earth, will
neverthelefs have changed the Point of Com-
pafs, with regard to each other) or, the E-
quator will never abandon the Places, which
have always been fituated under it, but its
Plan will turn with them round the Eclip-
tic, without any Change being made in the
Meridians, their Invariablenefs not proving
the fame Thing againft the Motion of the
Equator as in the former Suppofition. On
the contrary, refuming the fpheroidical Figure
of the Earth, which is the true one, its fo-
lid Parts manifeftly fuftaining themfelves, and
not having a Power to quit one another, the
moft remote from the Center will remain
always at the fame Diftance, and confe-
quently the Circumference of the Equator,
which has once environ'd them, will never
quit them ; fo that the Place of the Equator,
whether moveable or immoveable, can never
bring any Diforder on the Meridians. It
appears by this, that tho' the *Egyptian* Ar-

chitects might have had Orders to build the
Pyramids parallel to the four Cardinal Points
of the World, and they may have executed
these Orders with the utmost Exactness, this
does not hinder but the Angle of Intersection
of the Equator and the Ecliptic may conti-
nually vary, as much as we please.

There can be no greater Pleasure, than to
see the Credit of Truths, the most worthy of
Respect for their Antiquity, re-established, af-
ter having been contested in Ages so cir-
cumspect, and so little credulous as ours.
But it must be confess'd, that if the *Egyp-
tians* and *Babylonians* were the first Discove-
rers of the Decrease of this Obliquity, they
made the Discovery from Reasonings much
less certain, than those from which we attri-
bute this Discovery to them. *Herodotus* pub-
lished his History about a hundred Years af-
ter *Anaximander*, the *Milesian*, first found
out the means of measuring the Obliquity of
the Ecliptic: And this Invention having soon
after passed into *Egypt*, by the Voyages of
Cleostrates, *Harpalus*, and *Eudoxus*, the *E-
gyptians*, who could not but find this Obli-
quity less than *Anaximander* had found it,

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took the Advantage from thence to do honour to their Nation; as if the Diminution, and consequently the Measure, of the Obliquity of the Ecliptic, had been known among them for many thousands of Years, at the time when this latter was but just discovered by the *Greeks*. We have already said almost the same Thing of the *Babylonians*, who, equally jealous of the *Egyptians* and the *Greeks*, have advanced, by a parallel Calculation, to an Antiquity incomparably more absurd than that of the *Egyptians*.

But, whether this Motion of the Equator does, or does not exist, it is demonstrably certain, that it cannot be produced by any Mechanism, exactly the same with any discovered by the learned *Newton*. The Motion which most naturally resembles this of the Axis of the Earth, is the variation of the Moon's Inclination; which is of no less than 5 Degrees, 18 or 19 Minutes, when the Nodes of the Moon are in Conjunction, or Opposition with the Sun; and of 5 Degrees only, when these same Nodes happen in her Quarters. It is true indeed, that, by a natural Analogy, this great Philosopher attributes

butes a fmall alternative Motion to the Axis
of the Earth, by which the Angle of Inter-
fection of the Ecliptic and Equinoctial being
found in the Equinoxes, for Example, to be
23 Degrees, 29 Minutes, and is ftraiten'd in
approaching the Solftices, and enlarged again
from the Solftices to the Equator; fo that
at the Solftices this Angle, in its fmalleft Di-
menfion, is fome Seconds lefs than 23 De-
grees, 29 Minutes.

But thefe Alternatives of Diminution and
Decreafe produce not the circular Motion of
the Plan of the Equinoctial, from one Pole
of the Ecliptic to the other. This Circula-
tion then muft neceffarily depend upon fome
other Caufe, hitherto unknown, which we
fhould endeavour to difcover, provided the
Phænomenon be real.

That the Diminution of this Angle may
always equal its Increafe, the abfolute Center
of Gravity of all the Mafs of the Earth, muft
be the fame as the Geometrical Center of its
fpheroidical Figure; but this, very poffibly,
is not the Cafe. For if the Earth be ever fo
little lefs material on the Northern, than on
the Southern fide of the Equator, and if

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there arrive in the Body of this Planet, or on its Surface, any Change, which diminishes the Quantity of Matter in one Place, and augments it in another; it is evident, that the exterior Surface of the Earth, and the common Center of Gravity of its whole Mass, must change Position with regard to each other; and as the Geometrical Center of its spheroidical exterior Surface remains always the same, it is necessary that this Center also must change its Position, with regard to that of Gravity, whenever any Reason, manifest or not manifest, takes away ever so little Matter from one Place, and carries it to another. Now the two Centers, the Geometrical Center of its Oval Figure, and that of its general Gravity, should necessarily be in the same Axis of its Rotation, if this Rotation must be equal and uniform during 24 Hours, without being accelerated and retarded by Turns; which would be contrary to Experience.

To effectuate this Motion of the Plan of the Equator, it is sufficient then, that there should be, within the Earth, Matter which, by circulating continually, but flow-

ly, may continually remove the common Center of Gravity, with regard to the Surface of the Earth, becaufe the Axis of Rotation will always follow the fame Road as this Center.

If this Matter be not fuppofed to circulate, but to have a very fmall irregular Motion, the Plan of the Equator will alfo change its Pofition with the Ecliptic, but without any certain Rule, and may be fometimes nearer, fometimes farther from the Center; which, perhaps, may be more probable than a perfect Circulation. But none of all this Reafoning can have Place, till it fhall be proved in a manner altogether inconteftible, that the Approximation of the Equator and the Ecliptic, which the moft fkilful Obfervers pretend now to perceive, is real; and that there is no Illufion, either from the Refractions of Light, or from the Inftruments, in an Affair which is yet fo delicate, and fo little fenfible in Modern Obfervations, as to relate only to a few Seconds of Diminution; fo that it will not be till after many Ages of continued Obfervations, that any one will be able to fay,

T 3 with

with full Certainty, whether the Obliquity is variable, or how it is so.

The moſt ſhort and certain Method of terminating this Queſtion, would be to meaſure exactly the Elevation of the Pole from the Ruins of the antient City of *Syene* in *Egypt*. It is known, from the Report of *Strabo* in the laſt Book of his Geography, that this City was ſituated preciſely under the Tropic of Cancer, and that there was here a very deep Well, in which the Reflection of the Sun could never be ſeen, but juſt at Noon in the Summer Solſtice, the Sun ſhining vertically over the horizontal Surface of the Water, at the Bottom of the Well. *Strabo* adds in the ſame Place, that in travelling from *Greece*, this City was the firſt to be met with, where the Gnomons, or Columns erected vertically, had no Shadow at Noon-day once in a Year : So that here are two different Proofs, which aſſure us that in the Time of *Strabo*, or ſome Time before him, the Tropic of Cancer paſſed over the vertical Point of this City.

Now if in meaſuring at preſent the Latitude of the Place where *Syene* formerly ſtood,

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the Arctic Pole shall be found to be there elevated to 23 Degrees, 49 Minutes or more, this will be an indubitable Proof that the Chevalier de *Louville* has discovered the Truth, and that the Obliquity of the Ecliptic has diminished 20 Minutes in the Space of 18 Centuries. I say, 23 Degrees, 49 Minutes or more; for the Tower of *Syene* being renown'd before *Strabo*, on Account of this Property of which we are speaking, even as far back as the Time of the Prophet *Ezekiel*, who mentions it in the xxxixth Chapter of his Prophecy; it is apparent, that if the Obliquity of the Ecliptic was variable, it must have diminished five or six Minutes, in the same Proportion, from the Time of this Prophet to that of *Strabo*, during more than five Centuries; without reckoning what Diminution it might have undergone from the Foundation of this Tower to the Time of *Ezekiel*.

But if, on the contrary, the Pole is there found to be elevated but 23 $\frac{1}{2}$ Degrees or thereabouts, we must conclude, without Hesitation, that, during all this Series of Ages, the Obliquity in question has been constantly the same, or that its Diminution has not

T 4   been

been any Thing confiderable ; and that the Space comprized between the Equinoctial and the Ecliptic has been very little, if at all leffen'd. All the Difficulty would confift, in difcovering exactly the Situation of this antient City, in the neighbourhood of *Nile*, and the Ifland *Elephantine*. This Work would be a means to prevent the Cares of Pofterity, and of which to make a Merit with regard to our Children, for prefenting them with finifhed Demonftrations of a Truth, the clearing up of which may coft them many Centuries.

The Enumeration which we have undertaken to make here, of the principal Particulars which regard the Earth, with refpect to the Rank that it holds among the Planets, engages us to examine the Proofs of its fpheroidical Figure, which we have fuppofed true, and to fhew the Impoffibility of any Alteration of Meridians. We have already given a general Idea of it in Chap. XVIII. when, in proportion to the Extent and the divers Degrees of Gravity, we made mention of the Inundation of Waters towards the Regions of the Equator, which muft neceffarily refult from the Rotation of the Earth round its Axis, if it was exactly fpherical. But as that

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was not the Place to prove that this Diffe-
rence is so perceptible as to be measured,
we proceed here to shew what is known of
the Matter.

The Proofs, which we shall make use of, are
drawn partly from physical Arguments, and
partly from Experience itself. The physical
Arguments, which prove to us the necessity of
this Figure, suppose only, by way of Princi-
ple, the diurnal Motion of the Earth, of 23
Hours, 56 Minutes. If the Earth is exactly
spherical, the Velocity of the Rotation of all
weighty Bodies under the Equator will di-
minish their Gravity, or the Velocity of their
Descent, in proportion as it will differ less
from that which is necessary to make all
weighty Bodies circulate under the Equator,
without power ever to fall, or approach to the
Center of the Earth; or, to cause that all
Bodies which are under the Equator, should
be so many Satellites, which should turn by
their daily Motion in the Circumference of
the Equator, as the Moon revolves in her
Orbit. Now let us say, by the Rule of
Three; as the Cube of the Moon's Distance,
viz. 60 Semidiameters of the Earth, is to
the

the Cube of one only of thefe Semidiame-
ters ; fo is the Square of 39,343 Minutes,
which make a Lunar Month, to the Square
of the Minutes of the Revolution of the Sa-
tellites, or weighty Bodies, in the Circumfe-
rence of the Earth's Equator, fuppofing the
centrifugal Force exactly to counterbalance
the Gravity. The Product of this Calcula-
tion is, 84⅗ Minutes of Revolution: So that
if the Day of the Satellites confifted of 84⅗
Minutes, inftead of 23 Hours 56 Minutes,
which is 17 Times as much, there would
be neither Defcent nor Weight under the
Equator.

The fame Number of 84⅗ is found with-
out making ufe of the Moon, if we follow
the Theorem of Mr. *Huygens*, by which he
has found, that a Body, to turn circularly,
with a centrifugal Force equal to its proper
Gravity, muft furround the whole Circle in
the fame Time as a Pendulum, containing a
Semidiameter of the fame Circle in Length,
would employ in making two Vibrations.
Now to apply this Theorem to the Circle of
the Equator, and the Semidiameter of the
Earth, we need only fay, As three Feet, and
$\frac{17}{288}$ of

$\frac{12}{283}$ of a Foot, the Length of a Second-Pendulum, are to the Square of a Second, so 19,615,800 Feet, the Semi-diameter of the Earth, according to Mr. *Picart's* Measure, are to 6,412,430, which is the Square of 2,532 Seconds, or of 42 Minutes, 12 Seconds. A Pendulum of the Length of the Earth's Semidiameter, therefore, would make every Vibration in 42 Min. 12 Seconds; and consequently, to equal the Gravity to the centrifugal Force of the diurnal Rotation under the Equator, this Rotation muft neceffarily be finifhed in 84 Min. 24 Seconds.

But, as it is found 17 Times more flow, it is evident, that fuppofing the Surface of the Earth exactly fpherical, Gravity under the Equator exceeds its Diminution, or the centrifugal Force, 17 Times 17 Times, that is, 289 Times; which muft occafion the Velocity of Bodies Defcent under the Equator, to be to that of their Defcent under the Poles, as 288 are to 289; and a Second-Pendulum, which under the Pole would make 86,400 Vibrations in a folar Day, would make under the Equator but about 86,250: In the fame manner as a Second-Pendulum of *Paris,*

being

being tranfported under the Equator, and there making its curvilinear Defcents, or Vibrations, a little more flowly than at *Paris,* would be retarded 2 Minutes, 5 Seconds, or thereabouts, in a Day.

Mr. *Richer's* Experiment, made in the Ifland of *Cayenna,* Dr. *Halley's* in the Ifle of St. *Helena,* and thofe of the Perfons mentioned Page 196, having verified, except in a few Circumftances, this Diminution of Gravity under the Equator, which is a neceffary and indubitable Confequence of the Earth's diurnal Motion ; it remains, that we fhould furvey the Diforder which the centrifugal Forces of this fame Motion would caufe under the Circles parallel to the Equator, if the Earth was exactly fpherical.

Every one knows, that an exact Beam, being fufpended in the Middle, and left in Repofe, the Scales, or Weights, equally fufpended by Cords at its two Extremities, make thefe Cords, or rather the Middle of them, take Situations perpendicular to their Horizons, and which tend directly to the Center of the Earth. But if we give to this Balance a circular Motion, the Center of which is

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the Point of the Beam's Suspension, we shall see immediately that the Scales, or Weights, will fly out of the perpendicular Lines, in proportion to the Velocity of the circular Motion ; so that the Cords no longer follow the usual Direction of Gravity, towards the Center of the Earth.

Let us conceive now a great curvilineal Balance, whose Middle is suspended to one of the Poles of the Earth, and whose Extremities extend to an equal Elevation from the same Pole, on both Sides ; it is evident, that if the spherical Figure of the Earth, which we now examine, turns round on its Axis, and carries at the same Time this curvilineal Balance, in a circular Motion round the same Axis, the Weights, which being in Repose would incline towards the Center of the Earth, are removed from this Inclination, and out of perpendicular Lines, on both Sides. Thus the Sine of the small Angle of Deviation, comprized between the Perpendicular, and the new Direction of the Weights, will be near $\frac{1}{289}$ of the Product of the Sine, and of the Co-sine of the Elevation of the Pole, divided by the Radius.

It

It is manifeſt, that, without imagining this Balance curvilineal, this Reaſoning may be equally apply'd to all Plummets, which are uſed on the Surface of the Earth. It is in this manner that we find at *Paris*, and in a hundred other Places of the ſame Latitude, that a Pendulum in Repoſe would not tend perpendicularly to the Horizon, but would make with the Perpendicular an Angle of near 6 Minutes, which would be perceptible enough, if the Earth were exactly ſpherical: But as no Deviation is found in any Part of the World, it is ſufficient Proof that the Face of the Earth is ſuch as it ought to be, in order that the Direction of Gravity might be perpendicular, which can be only in a Spheroid*.

This ſpheroidical Figure produces yet another Change, with regard to Gravity, but of ſmall Conſequence. It is well known, that, without conſidering the Diminution of Gravity, of which we have been ſpeaking, Gravity itſelf varies according to the Diverſity of Diſtances from the Center of the Earth, even ſuppoſing there were no Rota-

* The Scales would fly out at the Æquator, whatever Figure the Beam is of, and ſo would not be perpendicular there.

tion.

tion. This is the Reafon why the Experiments of Pendulums, tranfported into different Climates, anfwer not with the utmoft Exactnefs to the Calculation which we have given above, tho' they all prove in general that Gravity differs fenfibly, and that it is always weaker towards the Equator, than towards the Poles. It is this alfo, which divides the greateft Geometricians in their Sentiments concerning the Proportion of the Axis of the Earth's Rotation to the Diameter of its Equator. Mr. *Huygens*, and after him *James Herman*, in his excellent Work *de Phoronomiâ*, have determined this Proportion, as of 577 to 578 ; but Sir *Ifaac Newton* gives it as of 229 to 230, about three Times more than the other. The Diverfity of thefe Meafures proceeds only from this, that Mr. *Huygens* confidered Gravity merely as a Force which impels Bodies towards one only Center ; whereas Sir *Ifaac Newton* confidered it as a Force by which all Bodies, and all the Particles of the Earth, even to the moft minute, are drawn towards one another *.

* Query then whether a Millftone within a Mile of the Earth's Center would not be drawn almoft as much up as down, and fo have lefs Gravity the nearer the Center, contrary to its Law of Increafe.   M A R S.

MARS.

The fourth Planet of our Syftem is Mars. His mean Diftance from the Sun is about 46 Million of Leagues. Of all the fuperior Planets, it is this which has the greateft Excentricity ; nor do we know any one, among all the celeftial Bodies, whofe apparent Magnitude is more variable; infomuch that his largeft Phafis exceeds his fmalleft, no lefs than 7 Times. In the Month of *Auguft* 1719, Mars being oppofed to the Sun, at only 2 or 3 Degrees Diftance from his Perihelion, we yet remember that many Perfons, who had no Tincture of Aftronomy, were aftonifhed to fee this Planet, and took it for a Comet, or a new Star, juft produced in the Heavens; in like manner as Venus was miftaken laft Year, when in the Month of *May*, having attained her higheft Meridian Elevation at the Beginning of Cancer, and yet being far enough from the Sun not to be eclipfed by his Light, fhe lanced her Rays along the fhorteft Road of the Northern Part of the Atmofphere.

As

As the great Excentricity of Mars renders his Motion apparently very unequal, it was of him principally that *Kepler* made use, to examine and verify the Discovery he had made, of the Equality of Areas described by every Planet in particular, in equal Times: And it was also by Mars that he found out and proved the Necessity there was to admit but very small Excentricities throughout the Heavens, not above half as large as those that had been established by the Antients.

Mars likewise, of all the Planets, is he which has the largest Atmosphere, in proportion to his Body, at least according to what we know hitherto; which is proved by the Alteration of the Colour of a fixed Star observed by Mr. *Romer,* as it approached and quitted the Disk of Mars: It grew sensibly pale on approaching this Disk, being yet above two thirds of its Diameter distant; and coming from behind the Planet's dark Body, did not recover the natural and usual Vivacity of its Light, till it came to the Distance of two thirds of the same Diameter.

U   Without

Without the Planet Mars, we should be altogether ignorant of the Distance and true Magnitude of the heavenly Bodies: And it was the celebrated Mr. *Cassini* the Father, who first thought of making use of the apparent Distance of this Planet from the nearest fixed Stars, when he is in Opposition to the Sun, in order to find the true Dimensions of our System. His horizontal Parallax, which in this Situation is large enough to be observed and calculated, without Danger of any remarkable Error, that is, between 26 and 27 Seconds in his Perihelion, furnishes us with a Method of calculating the horizontal Parallax of the Sun, and of the other Planets, which cannot be observed by themselves, on account of their Smallness. By the Spots in Mars, which we represent here as they appeared in 1719, it has been discovered, and we are convinced of it, that she turns round upon an Axis always parallel to itself, (like that of the Earth) in 24 Hours 40 Minutes.

Or,

South. North.

2 4

1 3
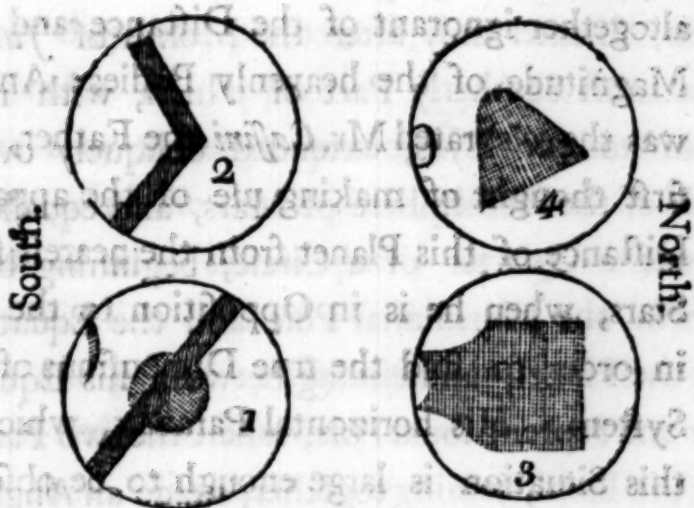
Or, that 36 Revolutions of Mars on his
Axis, equal 37 diurnal Revolutions of the
Earth.

The Spots of this Planet seem to be more
variable than those of all the others. The
obscure Bands, which were observed in 1704,
1717, 1719, do not agree among themselves,
neither with regard to their Situation, nor to
their Figure. In 1704 and 1717, an ob-
scure Band was seen, occupying more than a
Hemisphere of Mars, with this Difference,
that in 1704 it had a Point in the Mid-
dle, which was not found in 1717; and
that in 1717 it was farther from the Equator
of Mars, and nearer his Meridian Pole, than

*Remarks
on the Spots
of Mars,*

U 2   in

in 1704. In 1719, a crooked Band was
feen, formed only after the Month of *July*,
the moſt Southerly Part of which, with re-
gard to our Eyes, extended obliquely over
half of the Hemiſphere of Mars, and equalled
about a Quarter of a Circle, beginning be-
tween the Meridional Pole and the Equator
of the Planet, and ending between his Equa-
tor and Septentrional Pole, where the two Parts
of this Band, joining together, made an Angle,
as repreſented in Figure 2. Before the 13th of
July, only an obſcure rectilineal Band was
obſerved, ſuch as may be ſeen in Figure 1.

Beſides theſe obſcure Bands, certain con-
fuſed Spots, of an irregular Figure, as in Fig.
3 and 4, were diſcovered. Theſe were alſo
but temporary, and had hardly any thing in
common with thoſe that were obſerved be-
fore, except their Inconſtancy.

But the moſt conſiderable Spots of this
Planet, are thoſe which are obſerved near his
two Poles, of which however only one is
feen at a Time, and which are com-
monly more clear than the reſt of the Body.
Theſe Spots have been known near theſe 70
Years, and almoſt always either one or the
other

other of them may be seen; which proves
that they are permanent, and that the Vi-
ciffitudes of Apparition and Occultation
that they undergo, proceed only from some
Change in the Atmosphere of Mars, like to
that of ours, caused partly by the different
Constitution of the Air in Summer and Win-
ter, and partly by the different Quantity of
Rain and fine Weather, in different Parts of
the same Climate. It was thus that from
the 17th of *May* to the Month of *November*
1719, the Pole, which with regard to us is
the meridional, being illuminated by the Sun,
and consequently Summer reigning there, and
the Atmosphere there being rarified as much
as it could possibly be, the sparkling Light of
that pure Zone could strike our Eyes, while
that of the opposite Pole, which appeared
to the Observators in 1704 and 1717, with a
Lustre equal to that of the other, was hid from
our Sight by the Clouds, and congealed Va-
pours, which there changed the Atmosphere,
and rendered it less transparent. The Difference
of the Splendour of this Zone, one half of
which constantly preserved the same Degree
of Light, and the other on the contrary di-
U 3　　minished,

minifhed, difappear'd, appear'd again, feems no ill Refemblance of the diverfity of Weather on the Andes of *Peru*, where it never rains, and in the Ifland of *Borneo*, where it rains almoft every Day. This Effect may poffibly be produced by other Caufes; but it is always certain in general, that fuch a diverfity of Appearances proceeds from the different Conftitution of the Atmofphere.

JUPITER.

Jupiter, the largeft of all the Planets of our Syftem, defcribes in 4,331 Days, or (to count by a round Number) in 12 Years, an Orbit, the Semidiameter of which, in its mean Quantity, or mean Diftance from the Sun, is 156 Millions of Leagues. His Diameter is ten times larger than that of the Earth. The Weight of Bodies, which tend towards the Center of this Planet, or the Way that they make in falling directly upon his Surface, may be calculated.

Manner of calculating the Weight of Bodies, which defcend upon the Surface of Jupiter.

For this Purpofe, we are to fearch firft the Periodical Time of a Satellite, that fhould glance along the Surface of Jupiter, which is found by this Rule: As the Cube of 25 ½

4　　　　　　　　　　　　Semi-

Semidiameters of Jupiter, (the Diftance of his 4th Satellite) is to the Square of its Periodical Time, which is 16⅓ Days; fo the Cube of a fingle Semidiameter of Jupiter, is to the Square of the Periodical Time fought for. By this it is found, that fuch a Satellite, near the Surface of Jupiter, would finifh its Revolution round that Planet in 193 or 194 Minutes.

As all forts of Gravities are in direct Proportion of the Radii of the Circles, which the ponderous Bodies defcribe, without falling, and in reciprocal Proportion of the Squares of the Periodical Revolutions, the Quantity of the Gravity of thefe Bodies upon Jupiter is determined in this manner: As 1 Semidiameter of the Earth is to 10¼ of the fame Semidiameters, which are the meafure of that of Jupiter; fo 15¼ Feet of Defcent upon the Earth, during the firft Second, are to 158⅓ Feet of Defcent on Jupiter during the firft Second; if the Periodical Times of the Satellites, at the Surfaces of Jupiter and the Earth were equal. But having found above, that the Periodical Time of a Satellite of the Earth, near its Surface, is 84⅔ Mi-

nutes,

nutes, we muft proceed thence to this laft
Rule: As the Square of 193 ¼ Minutes, is to
the Square of 84 ⅔ Minutes; fo 158 ⅛ Feet
of Defcent, (if the two Periods are equal) are
to 30 Feet of the true Defcent upon Jupiter.
The fecond Pendulum then, in Jupiter, muft
be 7 ¼ Feet in Length.

The fame Confiderations fhew us alfo, that
Jupiter's polar Diameter, or Axis of Rota-
tion, is fhorter than that of his Equator, and
that this Difference muft be much more fen-
fible upon the Surface of Jupiter, than upon
that of the Earth. The diurnal Revolution
of Jupiter is 9 Hours and 56 Minutes; and
the Revolution of the loweft Satellite, which
could poffibly glide round him, having been
found to be 194 Minutes, which is in a man-
ner but the third of his diurnal Revolution;
its remaining Gravity, that is, as diminifhed
by the Centrifugal Forces under the Equi-
noctial of Jupiter, will be to its primitive
Forces fuppofing the Figure of Jupiter exact-
ly fpherical) as 8 are to 9. This then fhews
the Proportion of his fhorteft Axis to his
longeft, to be, within a Trifle, as 17 are to
18, if we calculate according to the Princi-
ples

ples of Mr. *Huygens* and *Herman*, and as 7
are to 8, if we follow those of *Newton*, found-
ed upon the mutual Gravitation of all the in-
terior Parts of the Planet. The Sentiments
of Sir *Isaac* seem to be supported by the Ob-
servations of Mr. *Cassini* the Father, reported
at the End of the 19th Proposition of the 3d
Book of his Philosophy, where it is said, that
the Diameter of Jupiter from East to West,
is visibly greater than from South to North.

The obscure Bands of Jupiter, extended a-
long his Disk, and always parallel, in a man-
ner, to his Equator, are represented in the
two following Figures.
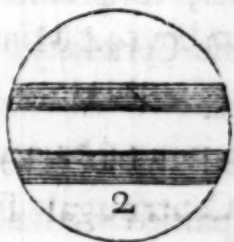
This Equator makes with the Orbit of Ju-
piter, an Obliquity but of 2 Degrees 55 Mi-
nutes; whereas ours is of 23 ¼ Degrees.
These Bands seem to be nothing but Exhala-
tions, which in rising, and joining together,

take

take a Circular Figure. It is true, they never are visible all entire at a Time; witness, in particular, that Meridional Band, which is produced, as it were, every six Years, and which always exhibits to us a black Spot, situate on its Northern Border; as it was observed in the Years 1665, 1677, 1713, in the Month of *December,* and in *April* of the Years 1672 and 1708. By comparing the antient Observations with those that have been lately made, it is remarked that these Bands, which at first appeared subject to Alterations altogether unaccountable, and which followed no Rule, have nevertheless Returns very regular, which may put us in a Capacity, hereafter, to predict their Appearances with the same Certainty, as we now calculate the Eclipses.

Remark on the black Spot of Jupiter. The Band which we have been speaking of, accompanied with a black Spot, appears commonly when Jupiter is in the last Degrees of Virgo and Pisces, near the Time of his Opposition with the Sun. What is most particular in it is, that these Appearances follow the true, rather than the mean Motion of Jupiter: For we are very sure, that from the

Oppo-

Oppofition of this Planet with the Sun in Pifces, to that which happens in Virgo, there are fix Years and a half, and five and a half only from this to the Return of the former, the whole together making 12 Years, the Time of Jupiter's periodical Revolution. This fhews us, that if we could remark all the Mutations that happen to thefe Bands, and which, without doubt, are effected at certain Signs of the Zodiack, as well as the Phænomenon of the black Spot, there would be room to hope, that the Order of their Return might be predicted, as well as that of the black Spot.

It is principally to this fame Spot, that we owe the Knowledge we have of the diurnal Revolution of Jupiter; the Velocity of which, in proportion to the Magnitude of his Body, would, doubtlefs, furprize us, if Mr. *de Mairan* had not demonftrated the Poffibility of it, in a learned Memoir, inferted among thofe of the Academy in the Year 1729, where he fhews, that the Difference there is between the Weight of the inferior Part of a Planet, which is turned towards the Sun, and that of the fuperior Part, which is turned from it,

it, is capable of producing such a Rotation from West to East.

This Spot is as well known to Astronomers, as the Situation of a celebrated City is to Geographers; and its Meridional Latitude upon the Surface of Jupiter, is determined at about 16 Degrees, as that of any remarkable Place may be upon Earth. It is true, that in observing the Revolutions of Jupiter, at the middle of his Parallel exposed towards us, they have not always been found quite the same, by the Difference of a few Seconds; though it be very natural to suppose them always equal to one another, as are those of the Earth: But this is of no great Consequence; and in an Enquiry of such a Nature, far from blaming the Astronomers, we ought to admire their Sagacity, and be very well pleased that they differ only in a few Seconds.

Why the Satellites of Jupiter appear sometimes less than ordinary. The Satellites of Jupiter, and chiefly the fourth being turned towards us, exhibit obscure Spots, which makes them sometimes appear much less than they usually seem: They even occasion the fourth, between whiles, to disappear entirely, when it is far

distant

diſtant from the Body and Shadow of Jupiter. But Aſtronomers have not yet determined, whether theſe Spots are produced ſuddenly, or whether it be the Rotation of the Satellites on their Axis, that diſcover them to us at one Time, and hides them at another: Though there ſeems to be much odds on the ſide of the Rotation, becauſe of the periodical Circumſtances that are ſaid to have been obſerved in the fourth Satellite. Or, perhaps, the Shadows of the Satellites themſelves occaſion mutually ſmall Eclipſes among them, which we can perceive only by a Diminution of their Luſtre: But this is a Point that has not yet been examined.

SATURN.

Saturn finiſhes his Courſe round the Sun in 29 Years and an half. If, counting roundly, the mean Diſtance of the Earth from the Sun is, as we have every where ſaid, 30 Millions of Leagues, it follows, by parity of Reaſon, that the mean Diſtance of Saturn from that Luminary is between 285 and 286 Millions of the ſame Leagues. This is the laſt Planet, and the moſt diſtant from the

Sun,

Sun, of any we know : At leaſt, there has not yet been diſcovered any Body beyond it in the Heavens, that has a conſtant Orbit, and turns circularly. The Comets, it is true, journey through Regions much more remote than Saturn: But as their Excentricity is much greater than that of the ordinary Planets, they make no Part of the Planetary Syſtem which we conſider in this Chapter. For even if we were to ſuppoſe that any one of them regularly revolved round the Sun, for Example, at 600 Millions of Leagues diſtance from the univerſal Center of our Syſtem, of what uſe would the Light and Heat of that Luminary be to it, at a diſtance where he could not appear larger than Jupiter and Venus appear to us? I have ſuppoſed 600 Millions of Leagues for the mean Diſtance of this pretended Body from the Sun, becauſe if this Diſtance were leſs, the Planets would embarraſs and attract one another too much by their reciprocal Gravitations.

Calculation of the Weight of Bodies, which fall upon the Surface of Saturn.

The Diameter of Saturn is near 10 Times larger than that of the Earth. By means of this we may calculate the Proportion of Gravity upon Saturn, with that which we experience

perience upon our Earth. His laſt Satellite
being diſtant from him between 53 or 54
of his Semidiameters, that is, the Radius of
its Orbit being between 53 and 54 Times
greater than the Semidiameter of Saturn, its
Revolution ought to be made in 79 Days,
22 Hours, or 1918 Hours. I ſay then, as
157,464, the Cube of 54 Semidiameters of
Saturn, are to one, or to the Cube of a ſingle
Semidiameter of the ſame Planet ; ſo 3,678,
742, the Square of 1918 Hours, are to about
23 $\frac{2}{3}$; the Square Root of which being ex-
tracted, the periodical Time of this Revolu-
tion is found to be 4 Hours, and $\frac{5}{6}$, or 4 Hours,
50 Minutes. Therefore a Body, which ſur-
rounded the Surface of Saturn, without being
entirely drawn to it, would require 4 Hours,
50 Minutes for that purpoſe, as we have juſt
now ſeen.

To find, in the next Place, how many
Feet the ponderous Bodies on the Surface of
Saturn deſcend in the firſt Second of Time, I
proceed thus. As 1 Semidiameter of the
Earth, divided by the Square of 84 Minutes,
and $\frac{1}{3}$, the Number found Page 282 is to 9 $\frac{1}{2}$
Semidiameters of the Earth, or to one Semi-
diameter

diameter of Saturn, divided by the Square of 290 Minutes, which we have juſt found ; ſo 15 Feet, the Deſcent of one Second upon the Earth, are to 12 Feet of Deſcent upon Saturn during the firſt, and ſomewhat more. But this Gravity of Bodies towards the Center of Saturn, ſuffers a conſiderable Diminution, by their Gravitation in a contrary way, towards the Cavity of Saturn's Ring, as we ſhall prove in the Sequel.

The following Figures repreſent to us the different Configurations of Saturn : 1. His round Phaſis, with a ſingle obſcure Band in the middle, cauſed by the Shadow of the Ring, and its obſcure Part, that receives no Rays from the Sun. 2. The ſame round Phaſis, with other Bands, in the manner they were ſeen in 1715. 3. The Phaſis of his Ring, which diſappears, and appears again after having been ſome Time inviſible. 4. That Ring in its greateſt Magnitude, with Bands that environ the Diſk of Saturn, as they were ſeen in 1696.

The
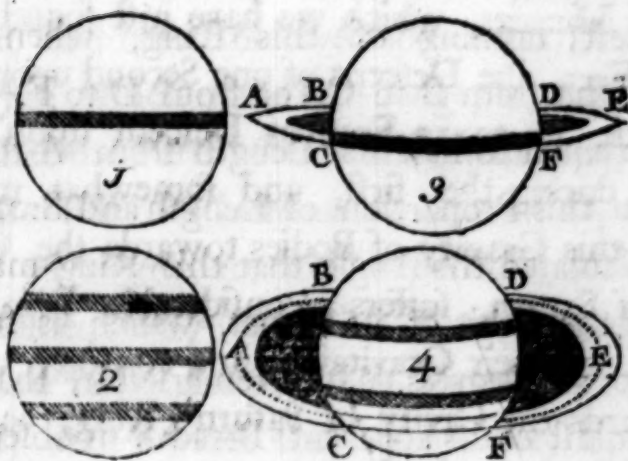
The exterior Diameter of Saturn's Ring, from one Extremity to the other, is to the Diameter of that Planet as 9 to 4, according to the Measure of Mr. *Huygens,* or as 11 to 5, according to that of Mr. *Cassini.* The interior Diameter, comprized between the two opposite Cavities, is to that of Saturn as 6 ½ to 4: For from the Body of Saturn to the Cavity of his Ring, there is just as much Space as from that Cavity to the outward Circumference. If Saturn himself be 30,000 Leagues in Diameter, then from his Surface to the Cavity in Question will be 9,375 Leagues, and from thence to the Extremity 9,375 Leagues also, instead of 8000, the usual Computation.

X   The

The fourth Figure reprefents to us the greateft opening of this Ring, when its Breadth, from B to C, or from D to F, appears equal to half its Length from A to E. From this Proportion of Length and Breadth is calculated the Angle that this Ring makes with the Orbit of its Planet, which is from 30 to 31 Degrees. It is remarkable, that in the midft of its apparent Breadth is obferved an obfcure Line, fuch as is marked out by the Points in the Figure. The Colour of its interior Part, which is neareft the Body of the Planet, appears more lively and luminous than that of its exterior Part, which is fartheft from the Body of the Planet, and the black Line, we juft now mentioned, makes the Separation of thefe Parts. Thus every Time that this Ring difappears, its exterior Part difappears firft; for the other continues vifible fome Days after.

In the Years 1714 and 1715, when this Ring was twice feen to difappear and appear, it was obferved, that its Oriental Part withdrew from Sight a Day or two fooner than the Occidental, and, on the contrary, that this fame Occidental Side difcovered itfelf a Day or two

fooner

sooner than the Oriental. Mr. *Caffini*, the
Father, had before obferved fomewhat like it
in 1671; which made him judge, with Rea-
fon, that the Parts of this Ring which are of
the fame fide, for Inftance A, B, and D, E,
of the 3d Figure, are not in the fame Plane,
and confequently that this Ring is thin-
ner, and more fharp at its Extremities A
and E, than towards the inward Cavity B, C,
or D, F.

There are two different Caufes, which oc- *Reafons of*
cafion our lofing Sight of this Ring. The *the difap-*
pearing of
firft is, that its Plan returning from being *Saturn's*
Ring.
oppofed to the Sun, its two Sides receive the
Rays of Light but very obliquely; which oc-
cafions that Light to become too feeble to
ftrike our Eyes. This happens when Saturn,
with regard to the Sun, is in 19 Deg. 45
Min. either of Pifces or Virgo. If there
were no other Caufe that produced the round
Phafis of Saturn but this, it would never con-
tinue above a Month; as was proved by Ob-
fervations made in the Years 1685 and 1701.
Towards the End of the Appearance, the
Shadow of the Ring upon the Body of Sa-
turn was perceived more clearly, and appear-

ed a little above or a little below the middle of his Difk, as reprefented in Fig. 1.

The fecond Caufe which renders the Ring invifible, is the Coincidence of its illuminated Part with the vifual Ray, which paffes on the Side which is not illuminated *. The Terms of this Appearance are lefs limited than thofe of the other before fpoken of : However, one is always fure of feeing it twice, when Saturn, oppofed to the Sun in 19 Deg. 45 Min. of Pifces or Virgo, is retrograde with regard to us. His Latitude, being obferved from the Earth, can differ one Time from another but very little; but this little is neverthelefs fufficiently perceptible, to advance or prorogue thefe Terms. In 1671, there were more than fix Months between the two Difparitions of the Anfæ, computing from the End of *May* to the 8th of *December.* The Place of Saturn, with regard to the Sun, was the firft Time in 13 Degrees of Pifces, and the 2d Time in the Beginning of the 20th Degree. In 1714, Oct. 12, the Day on which the Anfæ difappeared, Sa-

* The two Caufes are, the Plane of the Ring paffes either through the Sun, or though the Earth, in both which Cafes it becomes fcarce vifible.

turn with regard to the Sun was in the be-
ginning of the 17th Degree of Virgo; and
the 22d of *May* 1715, the Day of the fecond
Difparition, he was advanced to 21 Degrees
and an half of the fame Sign; but the Time
which elapfed between thefe two Difparitions,
was not more than 5 Months and fome Days.
Thus the round Phafes towards the begin-
ning of *July* 1744, and in the Month of
May 1760, will not be redoubled at all; and
we ought, confequently, to leave to Pofterity
the Obfervation of the Return of this Phæ-
nomenon.

Many People are curious to know if this
Ring be a continuous or folid Body, or if it
be not compofed of Satellites, which are fo
near the one to the other, that our Sight can-
not diftinguifh them. The laft of thefe two
Conjectures feems to me very probable. For
if it be objected, that the Motion of all thefe
Satellites, in one common Orbit, cannot fub-
fift without their interrupting each other, let
them be ever fo little excentrical; it will be
fufficient to anfwer, that this Motion is not
excentrical at all. If it be faid farther, that
the fuperior Satellites cannot finifh their Pe-

riods

riods in the fame Time as the inferior ones,
becaufe the Gravity, or centripetal Force of
their circular Motion, diminifhes in recipro-
cal Ratio of their Diftance from the Center
of Saturn; I anfwer again, that this Diffe-
rence of their Periods is in reality what is pre-
tended, but that the exact refemblance of all
the Satellites of one and the fame Order,
makes us regard this Collection of feparate Sa-
tellites as one continued Body.

There remains yet one fmall Difficulty more
to be removed. That Orbit, it will be faid,
far from being exactly circular, is elliptical,
its Grand Axis being always perpendicular to
a Line drawn from the Center of the Sun to
that of Saturn; becaufe, as all the Satellites
are but fo many Moons, they muft, for this
Reafon, obey the fame Laws of Gravitation
as our Moon. Now as the Orbit of the
Moon is neceffarily flatten'd a little in the
Conjunctions, as well as the Oppofitions, and
is more curve in the Quadratures, as we have
proved in Chap. XXII. it follows that the
fame Variation muft needs arrive in that of
the other Satellites. The Matter, therefore,
depends only upon the Difference of Saturn's
                                                    Gravi-

Gravitation upon the Sun, and that of his Satellites upon him; and it is of this Difference that we shall give the Measure in Chap. XXV.

The Bands of Saturn, which, being parallel with his Ring, shew us, that what causes them is elevated to a great Distance above the Surface of that Planet, because their Curvature is little or not at all sensible; prove indubitably, that Saturn is encompassed with an Atmosphere much more extensive than ours. But supposing, as above, that this Ring is composed only of an infinite Number of Satellites, it will not be necessary to extend it so far as them. And how vast soever this Atmosphere may be, it must be incomparably more transparent than ours, since the Fixed Stars, which are sometimes seen between the Ansæ and the Body of Saturn, suffer there neither Refraction nor Change of Figure, as in all other Atmospheres.

It is a very remarkable Thing, that among the 5 Satellites of Saturn, there are 4 which make their Revolutions in the same Plane with his Ring, and that only the 5th has a particular Orbit. The Inclination of the Orbit of

X 4 this

this laft, from that of Saturn, is but between 15 and 16 Degrees; whereas the 4 others circulate in a Plane, whofe Inclination from that of their principal Planet is 30 Degrees, or more. The Nodes therefore, of the one and the four, are a little different. Thefe latter have the fame Nodes as the Ring, namely, in 19 Degrees, 45 Minutes of Pifces and Virgo; but the other cuts the Orbit of Saturn rather at 15 Degrees, that is, in the 4th, or 5th Degree of the fame Signs.

Diminution of Saturn's Motion.

Before we leave Saturn, it is neceffary to remark one Particular more concerning his Motion, which has not yet been obferv'd with regard to the other Planets. All the more antient Obfervations, being compared together among themfelves, as well as with thofe of modern Date, give us an Eftimate of his mean annual Motion at 12 Degrees, 13 Minutes, and between 33 and 36 Seconds, at moft. But the modern Obfervations only, compared with one another, give that fame Motion as diminifhed fome few Seconds, reducing it to 12 Degrees, 13 Minutes, and between 20 and 29 Seconds. Other fmall Inequalities have been obferved in the Motion

tion of Saturn, since the Time of *Tycho-Brahe*; but which all agree to shew us, that his mean Motion is less speedy at present, than it was in the Time of the *Egyptians* and *Chaldeans*. Mr. *Cassini* has proved this beyond Dispute, in a Memoir presented to the Academy, *January* 10, 1728, by comparing the modern Observations, as well as those of *Ptolemy*, with a very antient Observation made the 1st of *March* of the Year 4485 of the Julian Period.

Though Sir *Isaac Newton* has proved, that when Jupiter is the nearest to Saturn that he possibly can be, he produces a manifest Change in the Motion of that Planet; yet the Diminution of Saturn's Motion is too sensible, and of a Nature too different from what it ought to be, for us to suppose that Jupiter is the only Cause of it. In fact, if there were not other Bodies that contributed thereto, how could it happen, that, in the greatest Proximities of these Planets, the Motion of Saturn should be sometimes accelerated, and sometimes retarded, as it undoubtedly is, according to the Observations reported by Mr. *Cassini?*

I

I believe therefore, that the Diminution of Motion, which Saturn more fenfibly experiences than all the other Planets, is caufed by the Attraction of many Comets *, which traverfe immenfe Regions of the Univerfe, beyond the Orbit of Saturn. Their Number and Magnitude are confiderable enough to have a fenfible Effect, with regard to the Gravitation of Saturn upon the Sun, which is equal but to a 9th Part of the Earth's Attraction towards the Center of our Syftem. Thus the Inequalities of this Diminution are more commodioufly explained by the different Proximities of the Comets, than by any other Caufe; and if the inferior Planets feel lefs than Saturn from their approaches, it is becaufe the attractive Power of the Sun has much more the Advantage over that of the Comets in thefe lower Regions, than it has in that of Saturn; as we have before faid.

* This may be true; but that is no reafon to believe it; and it may not be true, for the Comets being near to, or far from Saturn, are very accidental, and may caufe, increafe, as much as Diminution of Motion; for the Moon moves fafter in Conjunction when neareft the Sun, than in her Quadratures *cæteris paribus.*

CHAP.

CHAP. XXIV.

Of the Zodiacal Light, the Comets, and the fixed Stars.

Of the Zodiacal Light.

CERTAIN Hypotheses, by which the Phænomenon of the Zodiacal Light is explained, seem contrary to Sir *Isaac Newton's* Demonstrations concerning the Motion of Bodies in resisting Mediums. This is what we must endeavour to clear up; and it is principally for this Reason, that we make any mention of the Zodiacal Light in the present Work.

The Zodiacal Light is a Brightness like that of the *milky Way*, and sometimes more luminary: It extends almost the whole Length of the Zodiack, to 50, 60, 70, 80, 90, and sometimes to 100 Degrees and more from the Place of the Sun, on one Side and the other. Its Points, and a great Part of its luminary Arch, when it is not obscured by, or intermixed with our Twilight, seem to have an annual and diurnal Motion round the Earth.

Earth, fimilar to that which is vulgarly at-
tributed to the Sun. According to the learned
Remarks of Mr. *de Mairan*, drawn from the
Obfervations of Meff. *Caffini, Eimmart, Kir-
cher*, and others, 'tis at about the End of
Winter, and the Beginning of the Spring,
that the Evening is moft proper in our Cli-
mates to take a good Obfervation of this
Light; and the Morning towards the End
of Summer, and the Beginning of Autumn.
This Difference is an Effect of the different Po-
fition of the Ecliptic upon the Horizon, which
occafions the Point of Light in Queftion to
fall fometimes higher, fometimes lower.

The Angle at the Point, where the two
Sides reunite, is very unequal; varying from
20 Degrees, to 8 only. Mr. *de Mairan*, more-
over, reports certain Obfervations of Mr. *Caf-
fini*, who had found it of an irregular Figure,
and curve like a Sickle; and of Mr. *Facio de
Duilliers*, who defcribes the Sides with fuch
Points as are called in Geometry Points of
Re-curvature, or contrary Reflection, like
thofe of two Conchoids upon the fame A-
fymptote.

One

One of the moſt eſſential Particulars, that we know concerning this Phænomenon, and for which we are indebted to the great Sagacity of Mr. *de Mairan,* is, that the middle Section of this Light, or of the Matter that reflects it towards us, is the ſame as the Plan of the Sun's Equator, they both having the ſame Nodes with our Ecliptic, with which they make an Angle of 7 Degrees and a half. This is, at leaſt, a probable Demonſtration*, that this Matter belongs naturally to the Sun : It is not without Reaſon, therefore, that the Name of ſolar Atmoſphere has been given it. Tho' we muſt not confound it with the Atmoſphere that encompaſſes the Sun nearer his Body, and in which ſwim the ſolar Spots, making with it their periodical Revolution in 25 Days and an half.

The Figure of this outward Atmoſphere is a very flat Spheroid, whoſe greateſt Diameter is often 5, or even 8 or 9 Times larger, than that which is imagined from one Pole to the other. Its Extent at different Times is ſo unequal, that its ſuperior Point is ſome-

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* Demonſtration muſt be taken here in a large Senſe, extending to a probable Conjecture.

times

times much below the Orbit of the Earth,
and fometimes much above it. This inclined
Mr. *de Mairan* to believe, that this Spheroid
was very excentrical, and that its Apfides
had a Motion much more quick, and perhaps
lefs regular, than thofe of the planetary Or-
bits. It is evident then, that the Aphelion
of this Spheroid muft extend to between the
Orbits of Mars and the Earth, and that its
Perihelion muft terminate above the Orbit of
Venus, without reaching to that of the
Earth.

On this Occafion it is pertinent to enquire,
How it comes to pafs that the Earth and the
Moon, which both enter this folar Atmo-
fphere, feel no Refiftance from Matter,
that muft neceffarily have fome fort of Den-
fity ? Why the Velocity of their Motion is
not retarded ? Why, in a Word, the Orbit
of the Earth becomes not gradually lefs, from
Age to Age, as it muft infallibly do, if this
Motion was made in a Medium that refifts ?

It is an inconteftible Truth, and demon-
ftrated by Sir *Ifaac Newton* in the 4th Section
of the 2d Book of his Philofophy, that the
Denfity of a Medium being laid down in re-

ciprocal Proportion of the Diſtances from the Center of Motion, and the Gravity in double reciprocal Proportion of theſe ſame Diſtances, the circular Motion muſt change into that of ſpiral ; and that this Spiral is preciſely the ſame that *Deſcartes* and Father *Merſenne* firſt diſcovered ; namely, that which divides all the Radii proceeding from one only Center, under an Angle always equal. Therefore, if the ſolar Atmoſphere invelops the Earth and the Moon, the Years ought continually to grow ſhorter, becauſe the Orbit is continually contracted ; the Velocity both of the annual and diurnal Motion, muſt always diminiſh ; the apparent Diameter of the Sun will grow larger to our Eyes ; his Heat, with regard to us, will augment, till at laſt it deſtroys every living Creature upon Earth.

I think myſelf able to ſolve this Difficulty, in the following manner. All the ſmalleſt Parts of this Atmoſphere are as ſo many little Planets, which turn round the Sun almoſt in the ſame manner, and the ſame Senſe, as the great ones which we have hitherto known under that Name. Hence it follows, that they have themſelves, continually, Velocities

<div align="right">very</div>

very little different from thofe of the Earth at the fame Diftances from the Sun.

Every one fees, that an Affemblage of Particles, which turn with the fame Rapidity as a Body of confiderable Magnitude, that is encompaffed by them, cannot make any Refiftance to the Motion that this Body makes from the fame Principles. Every one fees alfo, that the Velocities of this Affemblage of minor Planets, if they fometimes refift a little the Motion of a greater that happens to be among them, thefe Velocities being increafed on the oppofite Side, will foon make it regain what it before had loft.

We are obliged, particularly, to the celebrated *Facio de Duilliers* for this Idea. Tho' that great Geometrician did not forefee the Inconvenience, that would arife from the Refiftance of this Matter with regard to the Motion of the Earth, the Moon, Venus, and Mercury ; he was yet the firft who let us know, that this Light was probably a fpheroidical Collection of fmall Planets ; as the Milky Way is only an infinite Number of fixed Stars, fo fmall that we cannot diftinguifh them.

But

But how is this? Some one will say, You have destroy'd the Vortices of *Descartes* in your 16th Chapter, and would you now establish another Vortex, entirely contrary to your Principles? This Atmosphere, which, according to you, turns inceffantly round the Sun, and whose Motion extends beyond the Orbit of the Earth, is it not a new Tourbillon, which you subftitute in the Place of that you have taken so much Pains to annihilate, in favour of *Newton*'s Philofophy? And, *Vortex* againft *Vortex*, why is not that of *Defcartes* as good as yours?

To this I anfwer, That the Vortices of *Defcartes* are very different from the circular, or elliptical Motion of the fmall Planets of this Atmofphere; to which I confent that the Name of Vortex may be given, if any one approves of it, provided he allows me at the fame time, that it has no Refemblance with thofe of *Defcartes* *. It is not neceffary to repeat here all the Inconveniences of thefe Vortices, which we have examined in the preceding Chapters; we will be content with

* Of that there muft be fpecial Care taken.

men-

mentioning only one Thing, in which they differ from that we are treating of. That the Vortices of *Defcartes* may, in Fact, have Force fufficient to carry round the Planets that fwim in them ; it is neceffary that the Planets fhould never have either more or lefs Matter than the Part of the Vortex that puts them in Motion ; which is contrary to Experience ; for their Motion in their Aphelia is much flower than in their Perihelia, and yet the Quantity of Matter which they contain, is always the fame. That which gives them their Rotation, therefore, is not a Power imprinted on them by any foreign Matter ; for if it were, that Matter being more large in their Aphelia, and more clofe in their Perihelia, it would produce a quite contrary Effect *. But our Vortex muft not be taken for a primary Spring of the planetary Motion, becaufe we confider Gravity, or Attraction, towards the Sun, as the true and primitive Caufe of that Motion. All the Ufe we make of it, in fhort, is only to retard the Motion

* But if the Diftance between the Sun and the Earth in the Vortex be fometimes greater, the Earth having broader Space will move flower therein.

of the Earth, and the inferior Planets *;
which is very different from imprinting a
Motion on them, like the Vortices of Des-
cartes.

An Objection much more real may be A *second*
made, from the Nature of circular or cur- *Objection.*
vilineal Motion, caused by some central Body
towards which all others are attracted. There
is no Doubt but that the Center of Powers
must be always in the same Plane in which
the Motion is made; for this is a necessary
Consequence of the Demonstrations, by which,
in the 19th Chapter, we proved the Equality
of Areas described in equal Times. How
then, it will be said, can it be possible that
two or more Bodies, whose Circulation be-
gins in different Planes, but at equal Distance
from the Sun, should avoid clashing together
somewhere, before they finish even their first
Revolution; since it is impossible that two
different circular Planes, which have the same
Center, should avoid intersecting each other
in two Points of their Peripheries? We do
not see, however, that this happens with re-

* But the Particles about it moving equally fast, as
Page 319, Line *ult.* they can be no Hinderance. See
also Page 327. l. 9.

gard

gard to the Matter that produces the Zodiacal Light, becaufe fuch a Clafhing as this would foon reduce it into one Mafs, and make of it a new Planet, according to the Theorems of Motion caufed by Percuffion, demonftrated fo clearly by Meff. *Mariotte, Huygens,* and *Herman.* Tho' certain Sparks of this Light obferved by Meff. *Caffini* and *de Quilliets,* demonftrate pretty clearly that this Clafhing of the little Bodies that compofe the Matter of it, is a very common Thing, this does not hinder that Matter from continuing to fub-fift, or from having its Viciffitudes of Dimi-nution and Increafe. But a Clafhing in the Interfection of two, or more Plans, fuch as that we have juft been fpeaking of, has ne-ver been remark'd, and certainly never will be.

To folve this Difficulty, we muft confider what would happen if there was a fecond Earth, of the fame Figure and Magnitude with ours, and if thefe two Earths were fo to touch one another at the two Poles of their common Orbit, as that the meridional Pole of the one was applied immediately to the feptentrional Pole of the other : It is cer-tain that the Center of the one and the other

would defcribe a particular Orbit, whofe Plane would not only not pafs thro' the Center of the Sun, but would even be diftant from it the whole Semidiameter of each.

I proceed farther. If in the Room of thefe two Earths we fuppofe 4, 6, 8, or more, we muft neceffarily recur to the fame Reafoning; and the Multiplication of thefe Bodies on every Side, will produce only a Multiplication of particular Orbits. But the common Center of Gravity of all thefe Earths joined together, fituated at the Point of Contact of the two middle Poles, will at the fame Time defcribe an Orbit that fhall hold the middle Place of all the reft, and pafs unavoidably thro' the Center of the Sun *.

To return to the little Bodies that compofe this Atmofphere; let us fuppofe all thofe which are at the fame Diftance from the Sun to touch one another, and there is no Doubt but they will unite eternally, as would do a Row of Earths, which had all equal Revolutions round the Sun. A fuperior or inferior Order of thefe Bodies, it is true, would make

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* Thefe are like the ingenious Hypothefes of *Defcartes*, that will not folve Difficulties except they be proved true.

a par-

a particular Revolution in a Period of Time ſferent from that of the preceding ; but they would be always in Union among themſelves, and without ever quitting thoſe of the ſame Rank. It ſignifies little whether the different Ranks, ſuperior and inferior, touch one another, or not, provided there be neither Inequality nor Friction, which may retard their Motion.

A third Objection. A third Objection, that may be made againſt the Motion of the ſolar Atmoſphere, we imagine is this: The periodical Revolution of the Sun's Spots, and conſequently of the lower Part of this Atmoſphere, with which theſe Spots evidently make their Revolution, conſiſts of 25 Days and an half, which are counted from the Time that one Part of this Atmoſphere is under any particular fix'd Star, to the Return of the ſame Part under the ſame Star.

Let us now compare the periodical Revolution of the Sediment of the ſolar Atmoſphere with the Time employ'd by the Parts ſituated in an Elevation equal to that of the Earth. To effect this, we begin by laying it down as a Principle, that all Planets, both

great

great and small, make their Revolutions in the same Region of Heaven in equal Times *. This is what no Person can deny, without contradicting Experience itself, which proves that the Disproportion of the Masses of Jupiter, Mars, and Mercury, creates no Disproportion in the Times of their periodical Revolutions.

The planetary Bodies or Particles of this Atmosphere, being at an equal Distance with the Earth, will make their Revolutions then in a Year; but to explain the Thing fully, we must have Recourse to this Rule of *Kepler* : As the Cube of 213 Semidiameters of the Sun, which make the mean Distance of the Earth from that Luminary, is to the Square of 525,949 Minutes, or a Year; so is the Cube of one single Semidiameter of the Sun, to the Square of between 169 and 170 Minutes. The Bottom, or Sediment, of the solar Atmosphere, ought then to turn in between 169 and 170 Minutes; but Experience teaches us, that its Revolution takes up 25 Days

* Abstracting from the Vicinity of other Planets, and Comets.

and $\frac{1}{2}$, as we have already seen; which makes
a Difproportion too obvious.

To fhew that this Objection has in it more
Appearance than Solidity, it will be fufficient
to fay that the folar Atmofphere is feparated
into two Parts by a Vacuum fo large, that
the fuperior Part can have no Communication
with the inferior. Now as this Separation
permits the inferior Atmofphere to follow the
Motion of the Sun round his own Axis, and
to have the fame periodical Time, it gives us
a Right to maintain that the fuperior Part,
that it may not fall upon the inferior, has
need of a planetary Motion, whofe centrifu-
gal Forces may counterbalance the centripe-
tal. Every one then muft be obliged to al-
low, that this fuperior Atmofphere ought to
have different Degrees of Velocity in its diffe-
rent Parts; otherwife the loweft would con-
tinually defcend toward the Sun, and the
higheft in like manner might be elevated above
Saturn.

Of COMETS.

Sir *Ifaac Newton* was the firft that gave us
a true Idea of the Comets Motion. Never-
theless

thelefs Mr. *Caffini*, the Father, had before
found the way to predict their apparent Si-
tuation, when they are not too near the Sun.
For, though he knew very well that their
Motion is curvilineal, he yet fuppofed the
Curvature to be fo little fenfible, that it might
be look'd upon as a right Line ; and by the
Help of this Suppofition, he found out a Cal-
culation that differs little or nothing from Sir
Ifaac's ; fince the more the equal Segments of
a Parabola remove from its Summit, the
more they approach to a right Line.

When Sir *Ifaac Newton* invented the Hy-
pothefis of the parabolical Motion of the Co-
mets *, to render its Calculation more geo-
metrical and lefs perplex'd, he did not actual-
ly believe that the Curvatures of their Way
were true Parabola's. On the contrary, in
the 42d Propofition of the 3d Book of his
Philofophy, he teaches the manner of finding
by Approximation the grand Axis of their
elliptical Orbits ; with this Reftriction how-
ever, that thefe Orbits are of a Figure fo ob-
long, that we cannot fee them all entire. We
do not fee the Comets therefore, but

* It was found to be matter of Fact from Obfervations,
and no Hypothefis invented by him.

when

when they are in their Perihelia, because all
the rest of their Course is made in Regions so
remote, that our Sight cannot extend so far.
What we see of the Orbit of a Comet, is of-
ten not equal to an hundredth Part of what
we do not see. For as the Comets do not
usually begin to appear till they are descended
to a Distance nearer the Sun than Jupiter,
and farther from him than Mars. When they
return into the superior Regions, and attain
a Distance from the Sun equal to that of Ju-
piter, their Light is so weak that it is per-
ceived with the utmost Difficulty.

As a Parabola is nothing else but an Ellip-
sis, whose Center is infinitely remote from
its Focus, this Term is used, according to
Sir *Isaac's* Rules, in the room of Ellipsis,
when the precise Measure of the two Axes is
not known, provided that the greater Axis ex-
ceeds the lesser at least 20 Times. Other-
wise, it would not only be a considerable
Fault to prolong the parabolical Motion be-
yond the Distances in which Comets are visi-
ble, but we should moreover deprive our-
selves thereby of the Hope of ever seeing
them again.

Thus

Thus the Motion of the Comets round the Sun so far resembles that of the Planets, that though the former approach much nearer that Luminary than the latter, they are not liable to impinge upon him, when the Curve of their Motion becomes perpendicular to its Distance. For the centripetal Force being less than a third, in proportion to the Distance of the Sun and the Velocity of the Perihelion, the Planet or Comet is no sooner arrived at its greatest Proximity to the Sun, but it begins to recede from that Luminary again *.

Why the Comets and the Planets do not impinge upon the Sun in their Perihelia.

Its Atmosphere, Duration, Tail, and Return, are the most remarkable Particulars relating to a Comet.

The Atmosphere of a Comet differs from that of an ordinary Planet, in that it is larger in proportion to the Body it surrounds. Some of them have 15 Times as much Diameter as the Comets themselves. Likewise the same Atmosphere is not always equally extended, because it diminishes and increases by Fits.

* But when its near the Aphelion the centrifugal Force is far greater than the attractive Force, but all on a sudden the attractive Force exceeds the former.

It

It is not well known yet, whether these Diminutions and Augmentations return regularly at the same Distances from the Sun and the Perihelion. For, according to the Observations of *Hevelius*, cited by *Newton*, these Atmospheres diminish in proportion as they come nearer the Sun, and augment according as they remove from him. On the contrary, Mr. *de Mairan* assures us, that they encrease on approaching the Sun, by the Parts of the solar Atmosphere that they carry away with them as they pass along : Both these Opinions seem founded on this, that the Atmospheres of the Comets probably diminish till they meet that of the Sun, from which they acquire new Materials. Moreover, these Atmospheres, containing an Air like ours, must always occupy more Space when they descend towards the Sun, than when they ascend from him ; because this Air rarifies extremely when they descend, and condenses in like manner when they ascend.

The Duration of the Comets is proved, according to Sir *Isaac*'s reasoning, by the Degrees of Heat they undergo in their Perihelia.

<div align="right">This</div>

This Philosopher made a Calculation, that the Comet in 1680, which passed by the Sun's Surface at the Distance only of a 6th Part of his Diameter, must contract a Heat 2000 times greater than that of red hot Iron. Whence he concluded that this Body must be very compact, and as antient as the World; otherwise it could not have resisted the Rays of the Sun, in that Proximity, but must have evaporated.

As the Sentiment of Sir *Isaac* is a kind of Paradox to those who have made no Progress in these Matters, it is proper to see how he supports it. The Line comprised between the Center of the Sun and the Comet in Question, in its Perihelion, was to the Radius of the Earth's Orbit as 600 to 100,000. The Heat perceived on Earth then, was to that of the Comet as 360,000 to 10,000, 000,000, or as 1 to 28,000. Now as the greatest Heat in Summer is to that of boiling Water but as 1 to 3½, and as this last is yet four Times less than that of red hot Iron, he found that the Iron's Heat was to that of the Comet as 14 to 28,000, or as 1 to 2000.

If

If a Ball of red hot Iron lofes its Heat in one Hour, and the Time neceffary to cool the heated Spheres be in proportion to their Diameters and Degrees of Heat ; it will require 108 Millions of Years to cool the Body of that Comet, provided it be fo large as our Earth.

Why the Orbits of the Comets are fo ex-centrical.

This Reflection difcovers to us, and makes us equally admire, the Wifdom of the Creator. Nothing could fubfift in the Comets, if they had not a Heat fufficient for the Prefervation of their Matter. Nature, to the End fhe might give them as much Heat as they have need of, even in Regions the moft remote, where a circular Motion, or one but little excentrical, would have deprived them of the Sun's Heat, has augmented fo confiderably their Excentricities, that they contract fuch a Heat in a very fhort Time, as makes them enjoy a temperate Warmth during the reft of their Revolution. But if, on the other Side, there are animate Creatures in the Comets, as Mr. *Huygens* has proved there are in the Planets, they muft of neceffity retire into the interior Cavities of thefe Comets,

to fecure themfelves from that general Conflagration on their exterior Surfaces.

To confider the irregular Figure of fome Comets, one would judge that they do not turn upon their Axes; becaufe they cannot have this Rotation without having at the fame Time a fpherical, or a fpheroidical Figure, and one Body only enclofed in their Atmofphere. But fome of them have been feen, that were neither exactly fpherical nor fpheroidical; others, that feemed to be an Affemblage of divers Bodies, of different Figures and Magnitudes; which no Ways agrees with a diurnal Motion, and renders the Pofition of their Axes extremely variable. Befides this, their Tails, which are very unequal, and change almoft every Moment, muft either fenfibly retard, or totally ftop the Rotation in Queftion; which has not yet been obferved.

But if the Comets do not turn round on themfelves, the fame Part, before and after their Conflagration, muft be almoft always expofed to the Sun; and confequently, one Part only of their Spheres can be habitable, becaufe that continually fees the Sun, and the

other

other is buried in a Night of many Years, or many Ages Duration; which, nevertheless, does not hinder but this Hemisphere may have as much Heat as that which is illuminated. To explain this Paradox, we will add to what has been said concerning their Excentricity, Page 334, that the Heat which they may receive from the Sun in their Aphelia, is not the 10,000 Part of what is felt at the Poles of the Earth; and that the Heat contracted in their Perihelia, must afterwards continue equal over all their Surface.

The Smoke which issues from the Comets, and which disperses itself in the Regions of Heaven that they traverse, composes their Tails. They begin to form themselves a little before the Comets arrive at their Perihelia, and from the Time that the Sun's Heat is intense enough to enflame the combustible Matters on their Surfaces, when the Smoke makes a Breach through their Atmospheres. It is true, however, that this Conflagration begins a little before we perceive the Smoke; but we consider here only the Instant when we first discover their Tails.

They

They are never longer than when the Comets afcend from their Perihelia, after which they diminifh daily, even at the Time that they approach the Earth. From thefe Degrees of Augmentation and Diminution, the learned *Newton* found that the Tails of Comets were only Smoke. This was farther confirmed by their Direction, which extends always towards the Parts oppofite to the Sun. We cannot give a more fenfible Comparifon of the Times, than that which our Philofopher has given, tho' it will require to be a little more circumftantiated.

Let us conceive to ourfelves the Idea of a lighted Torch, with the Wick reverfed, that, by a projectile Motion, furrounds the Earth; all its Smoke will afcend, and endeavour to get away from the Center of the Earth, notwithftanding this Inverfion. Farther, this Smoke will fo incline towards the Regions contrary to the Motion of the Torch, that the upper Part of it will feem to move more flowly than the lower: And, what is yet more remarkable, the Smoke will appear broader at Top than at the Bottom; as we fee by that which iffues out of Chimnies, which al-

Z ways

ways occupies more Space than it did before. All this agrees perfectly with the Phænomena of these Tails. The kindled Part of a Comet, which is that towards the Sun, drives its Smoke to the Parts opposite to that Luminary.

This Smoke has always some Curvature at its Extremity, which is reclined, or beat backwards, in proportion to the Length of the Tail; the longer this, the greater the Curvature; and the Curve Extremity is also larger than that which adheres to the Body of the Comet. This Comparison is so exact, that it leaves no Room to question but the Tails of Comets are real Smoke, caused by their Conflagration on approaching the Sun.

Mr. *de Mairan* very ingeniously assigns another Cause to the Tails of Comets, which we shall here insert, and endeavour to reconcile, as much as possible, with that which *Newton* has just now furnished us with. He remarks, that the Comets, as they pass by the solar Atmosphere, amass not only Particles which incorporate with them, as was before observed, but others also, which cannot suddenly follow the Comet, but detach themselves from it,

it, to form behind it a kind of Cone : Which
Figure, according to that great Philosopher,
being rejected or pushed by the celestial Mat-
ter, takes a Rout contrary to that of the Co-
met, as the Hair of a Man's Head, when he
walks, or runs, against the Wind, takes a Di-
rection contrary to that of the Head.

This Comparison is good with regard only
to the growing Tails of Comets, which have
not yet attained their Perihelia. For the co-
nic Collections from the solar Atmosphere,
drawn by the Comets after them, and the Be-
ginning of their Smoke, which are the two
Causes assign'd, as they both produce the
same Appearances, so they both must have the
same Effects upon our Sight. But beyond
their Perihelia, the celestial Matter directs that
which hangs on the Comet towards the Sun.
Therefore no one ought to be surprised, if
the Smoke of Comets is much more easily ob-
served, than this little Assemblage of Matter
that they carry along with them.

The periodical Revolutions of the Comets,
is what at present engages the principal Atten-
tion of many Philosophers. The Return of
that which appear'd in 1682, may be pre-

dicted

dicted for the Year 1757 or 1758.   There is
the greateſt Room to believe it was the ſame
that was ſeen in 1607; for there was ſo little
Difference found between the Velocity, the
Nodes, and the Inclination of the one and
the other, that it may be conſidered merely
as an Effect of the Attraction of the Planets,
and the other Comets.

Mr. *Caſſini* has diſcovered, that almoſt all
theſe tranſient Bodies have a Road different
from that of the Planets.   It has hitherto
been unknown of what Conſequence this new
Zodiac, and this periodical Return of the
Comets, may be for the Preſervation of the
human Species.   Imagine, for Example, that
there are fortuitous Bodies, which accidentally
fall in with our Ecliptic : What a Diſaſter
would it be for our Earth, if unhappily ſhe
ſhould find herſelf in the ſame Point ?   The
Idea of two Bombs, which burſt on claſh-
ing together in the Air, is infinitely be-
low · what we ought to have of ſuch a Ren-
counter as this.   Happily for us, it has been
diſcovered that the greateſt Part of the Co-
mets, in the Nodes of their Orbits, are much
leſs remote from the Sun than either our
Earth,

Earth, Venus, or Mercury. This is the whole Foundation of our Security, and hence we learn how many Thanks we owe the supreme Being for so great a Benefit.

The Comets, by their unexpected Returns, sometimes produce Phænomena altogether surprising, when their Cause is unknown. Such was, according to Mr. *Whiston,* that extraordinary Eclipse of the Sun spoken of by *Herodotus,* which arrived in the Spring of the Year 4334 of the *Julian* Period, when *Xerxes* departed from *Sardis,* the Capital of *Lydia,* where he had spent the Winter. Such was also, according to *Wolf,* that of the Moon, which happened in the 14th Century, that celebrated Mathematician having shewn in his Elements of Physic, after *George Phranza,* that this Phænomenon could not happen naturally, the Moon being then in one of her Quarters. To conclude, such was that of which *Gregory Abulpharachius,* an *Arabian* Author, makes mention in his History of the oriental Dynasties, where he remarks, that under the Emperor *Heraclius* the Sun appeared all over the Earth, for the Space of three Days, as red as Blood, which might

well

well happen, by the Interpofition of a Comet's Tail.

Of the FIXED STARS.

As Sir *Isaac Newton*'s Syftem feems to contradict itfelf with regard to the fixed Stars, which, according to him, attract one another, and yet remain immoveable; we muft begin with explaining his Sentiment, and fhewing, that it does not imply any Contradiction at all.

The Diftance that there is between one fix'd Star and another is fo immenfe, that they could not defcend towards each other fo much as one fingle League in a Year. This is what will be feen in the following Calculation. 1ft. Ponderous Bodies, according to our Computations, Page 244, defcend (if we keep to round Numbers) at leaft 1,260,000 Feet upon the Surface of the Sun, during the firft Minute. 2dly, According to *Huygens*, the neareft fixed Stars to the Sun are diftant 28,000 Semidiameters of the Earth's Orbit, or thereabouts, that is to fay, above 5,600,000 folar Semidiameters, the Square of which is 31,360,000,000,000. The neareft fixed Star to the Sun, therefore, advances towards him

the

the $\frac{1260000}{313,0000000000}$ Part of a Foot, during the firſt Minute. But if, inſtead of this Fraction, we reckon the $\frac{1}{250000}$ Part of a Foot, we ſhall find for the firſt Year 11,000 Feet, which is very near the exact Number, with regard to the Sum total.

Sir *Iſaac Newton* has demonſtrated, in the 12th Propoſition of the 3d Book of his Philoſophy, that the common Center of Gravity of our planetary Syſtem, would be diſtant one ſolar Semidiameter from the Center of the Sun himſelf, that is about 4,000,000,000 Feet, if all the Planets were on one Side, and this Luminary on the other. What Diſproportion then, between the Diſorder of the Sun, occaſioned by the Planets that encompaſs him, and that which proceeds from the fixed Star that is neareſt to him ! even no leſs than between 11,000 and 4,000,000,000 Feet !

Now as the Sun is ſometimes on one Side of the univerſal Center of his proper Syſtem, and ſometimes on the other, and as the ſame thing happens to every fixed Star, with regard to the unknown Planets that ſurround it, the manifeſt Reſult is, that theſe luminous Bodies are reciprocally attracted by Forces

Z 4   much

much weaker than those which sometimes draw them from each other. These Vicissitudes then, of Proximity and Distance, are what always retained the fixed Stars in their natural Situation, without any Possibility of their ever falling upon one another.

As certain fixed Stars, which, according to the Observations of *Montanaro*, have disappeared within some Years past, and have not destroy'd the Stability of those which remain, it may be proper to enquire what may be the Causes of their disappearing *. The celebrated *Wolff* specifies three of these Causes in his Physicks.   1st. They may, according to him acquire Motion, and thereby withdraw themselves from our Sight.   2dly, By falling back into Chaos, they may burst, and evaporate entirely.   3dly, They may lose their Light, either altogether, or in such a Degree as to make them invisible to us.

The first of these Causes appears by so much the less probable, as the Attraction of

---

* The Stars that disappear cannot be called fixed; they are more likely Planets revolving about a fixed Star, which appear when they come near the Earth, with their luminous Part towards it, as that in the Whale, the Swan, and Hydra, which have their periodical Returns.

the

the fixed Star, which should disappear, would become stronger, and would precipitate all the Bodies that might environ it, one upon another. The second is not more probable, since this pretended Dissolution must change the reciprocal Gravitation of the Stars that were nearest to that which should evaporate; so that, for the future, they would have nothing to keep them in Equilibrium. We will therefore adopt the third, because by supposing the Stability of the * fixed Star, we suppose it to preserve all its attractive Force.

The same Judgment should be made of the periodical Returns of the Apparition and Occultation of certain Stars, that have been observed in the *Whale*, the *Swan*, and the *Hydra*. For tho' the Part which is towards us be more or less luminous, and we sometimes lose Sight of it entirely, yet they never quit their Places, but their Attraction continues to preserve the Equilibrium of the Universe.

It follows, from all these Arguments, that the reciprocal Gravitation of two fixed Stars, does not diminish precisely in the inverse or reciprocal Proportion of the Squares of their

* Then they disappear, because their Light is put out; but what puts it out?

Distances,

Diftances, efpecially near the common Center of their Gravity. It follows alfo, that the Law of Gravitation may vary, as may be feen at the End of Chap. VII. where the different forts of Attraction are fpoken of. The Action of the Loadftone upon Iron * in inverfe Reafon of the Cubes of their Diftances, and that of tranfparent Bodies upon the Rays or Atoms of Light, fufficiently prove, not only the Poffibility, but the Reality of what is here advanced.

* Action of the Loadftone on Iron, being mechanical, cannot be called Gravitation.

C H A P.

CHAP. XXV.

Of the second Inequalities of the Motion of the Satellites, and the Phænomena that depend thereon.

AFTER having given the Reader, in the XXIst Chapter, several Particularities of the Moon's Motion, to establish the Necessity of Attraction; it remains that we should shew in this, that the Theory of these Inequalities, caused by this Mechanism, is entirely conformable to Observations.

Sir *Isaac Newton* has assigned three Causes of these sorts of Irregularities. He maintains, 1st. That the Force which draws the Moon towards the Earth, is less than that which draws these two Planets towards the Sun; 2dly, That, considering the Orbits as exactly circular, the Force which attracts the Earth towards the Sun is always equal, whereas that which draws the Moon towards the same Luminary is greater in her Conjunction than in her Opposition: and 3dly, That the Lines of Attraction, which tend towards the Sun,

contract

contract themfelves in Proportion as they come nearer him, and always augment the Gravitation of the Moon towards the Earth, efpecially when that Planet is in her Quadratures.

If we fuppofe, for Example, that the Moon is in Conjunction with the Sun ; it will appear, that, by her Gravitation only towards the Earth, fhe will defcribe, in 10 Hours 20 Minutes, a fmall Arch, of 100 fuch Parts, whereof 1000 compofe the Radius of her Orbit, and 336,000 make her Diftance from the Sun. Now if, during this Time, the Moon defcribes 100 Parts of her Radius, it follows that (according to the Rule of circular Motion, mentioned Page 331, Line 7.) as 1000 Parts of this Radius are to 100 (a Line which differs little from the Arch in Queftion) fo the Number 100 is to 10, the uniform Defcent of the Moon towards the Earth. But if we would determine the Defcents of the Earth and the Moon towards the Sun, we muft conform to the Rules given Page 233, and proceed by this fhort Operation. 1ft. As 1 (the Moon's Diftance from the Earth) divided by the Square of a periodical

dical Month, is to 337, divided by the Square
of a Year ; so 10 (the Descent of the Moon
towards the Earth) is to 19, the Earth's
Descent towards the Sun. 2dly, As the
Square of 336,000 is to the Square of 337,000 ;
so 19 (the Earth's Descent towards the Sun)
is to $19\frac{12}{168}$, the Moon's Descent towards
that Luminary. There must then be $\frac{12}{168}$ of
one single Part of the Moon's Radius, taken
from 10 Parts of the same Radius, to find
her true Descent towards the Earth ; which
will in Fact be only $9\frac{42}{100}$; whereas it would
be 10, without the particular Action of the
Sun upon that Satellite. By the same Reason
the Moon's Distance from the Earth, which
was laid down at 1000 Parts, will be found
to consist of $1000\frac{12}{168}$ Parts ; which contri-
butes yet more to the Diminution of her
Gravity.

Whilst the Moon is yet so little distant
from her Conjunction, the Force which im-
pels her towards the Line of the Syzigiæ is not
at all considerable ; but it augments in pro-
portion as this Planet comes nearer her Qua-
drature. When, on the contrary, she has at-
tained her Quadrature, that second force, which

acts

acts in the fame Senfe as her Gravity towards the Earth, drives her always towards our Globe, till, being in her Oppofition, fhe finds herfelf diftant from it only 1000 Parts.

By the Mixture of thefe two Forces, the Diftance of the Moon from the Earth, in her Quarters, will be from 1023 to 1024 Parts, continuing the Calculation, which we have before fketch'd out, and remembring the Obliquity arifing from the Configuration of that Satellite with the Sun. As for the reft, we do not here any longer admit of Excentricity; if we did, the Orbit would be always oval, tho' of different Breadth and Figure, according to the Capacity of the Angle comprifed between the two Lines of the Apfides and the Conjunctions. For fuppofing this Angle nothing, the Excentricity becomes larger than if we fuppofe it of 90 Degrees; fince in the firft Cafe, the grand Axis is 2000, and in the fecond, 2047. Our Dimenfions, it is true, are not the fame with thofe of Sir *Ifaac Newton*: But as that great Man acknowledges, towards the End of his Preface, that his Lunar Theory hath its Imperfections, we have thought it fufficient to keep clofe

to

to his Principles, without subjecting ourselves to his Mensurations.

As to the Satellites which compose Saturn's Ring, we shall find, by a similar Calculation, that the grand Axis of their Orbit is to the small, as 1000½ to 1000, and that, consequently, this Orbit is 2,250 Times less elliptical than that of the Moon.

But to satisfy those who may doubt whether our Calculation be conformable to Observations, let us return to the Excentricities, which we have only pointed out before, and shew, by a new Computation, that they agree with the apparent Diameters, and horary Motions of the Moon.

When the Apsides fall in the Syzigie, the greatest Excentricity of the Orbit being, according to the most famous Astronomers, to the mean Distance of the Moon, as 67 are to 1000, one may easily conceive that the Apogæon is distant from the Earth 1067, and the Perigæon 933. By the same Reason, when the Apsides are at the Quarters, the Excentricity in question being but 44, and the mean Distance 1024, that of the Apogæon to the Earth ought to be 1068, and that of the Perigæon 980. Now

Now the apparent Diameter of the Moon in her Apogæon, confifts (to count without Fractions) of 29 Minutes and 40 Seconds, and never varies more than from 1067 to 1068. On the contrary, it varies always in her Perigæon from 34 Minutes to $32\frac{1}{2}$ Minutes, that is, in reciprocal Proportion of 933 to 980. Therefore the Diftances of the Apogæon and the Perigæon are precifely, according to our Calculation, in reciprocal Proportion of thofe apparent Diameters, that have hitherto been found by Obfervation.

The Exactnefs of thefe Relations is no lefs proved by her horary Motion. For while the Areas defcribed are equal, thefe Motions are always in reciprocal Proportion of the Squares of Diftances. Thus, as the Square of 933 is to 29 Min. 20 Seconds, the Horary of her Apogæon ; fo is the Square of 1067, agreeably to Obfervation, to 38 Minutes, the Horary of her Perigæon in the Syzigie. And if the Square of 980 produces 29 Min. 20 Sec. that of 1067 will produce, conformably to Obfervation, 35, for the Horary of her Perigæon in the Quarters.

It

It appears alfo, that, by the fame Laws of Gravitation towards the Sun, the Moon, which is not in the Ecliptic, ought to approach it even to the Syzigiæ ; becaufe, according to the Angle of her Orbit with ours, her Latitude continually grows lefs than it ought to be. This Latitude then diminifhes every Moment ; and whereas in the Quadratures, near the Nodes, it was of 5 Deg. 18 Min. it is barely of 5 Deg. both in the Conjunctions and Oppofitions ; which renders the Surface of the Orbit curvilineal. If, on the contrary, the Nodes are in the Syzigiæ, the Action of the Sun doth not diminifh the Latitudes, the Angle in queftion remains always the fame, and the Orbit becomes a plain Superficies. As to their Motion, it is then extremely flow, becaufe the Action of the Sun, which, during a pretty confiderable Space of Time, is almoft parallel to the Diftance of the Moon and the Earth, never flackens at all : But it is not the fame in the Quadratures, where they have a confiderable Retrogradation. For the Moon meets them every Month about three Hours fooner, efpecially at the Middle both of her Increafe and Decreafe, where the Diffe-

rence

rence of her Gravitation, and of that of the Earth, towards the Sun, augments and diminishes more swiftly than any where else.

Motion of the Terrestrial Poles, Page 258.   The Precession of the Equinoxes, as well as the Retrogradation of the Nodes, is moreover an Effect of these Irregularities, tho' much more slow ; because the Quantity of terrestrial Matter, which is under the Equator, differs very little from that of the Meridians; and because that little *Excess*, under the Equinoctial, supplies the Place of a Satellite, or a Ring, such as that about Saturn.

There are some other Causes, which render the Motion of the Satellites a little irregular, but whose Effect is not considerable, except with regard to themselves. It has been remarked, that the Apogæon of the first and fourth Satellite of Jupiter is constantly the same with that of their central Planet ; and that it is not till after many Revolutions of this latter, that the Orbit of the 3d Satellite returns to the same Inclination. Thus the Nodes of these four little Bodies have not varied,
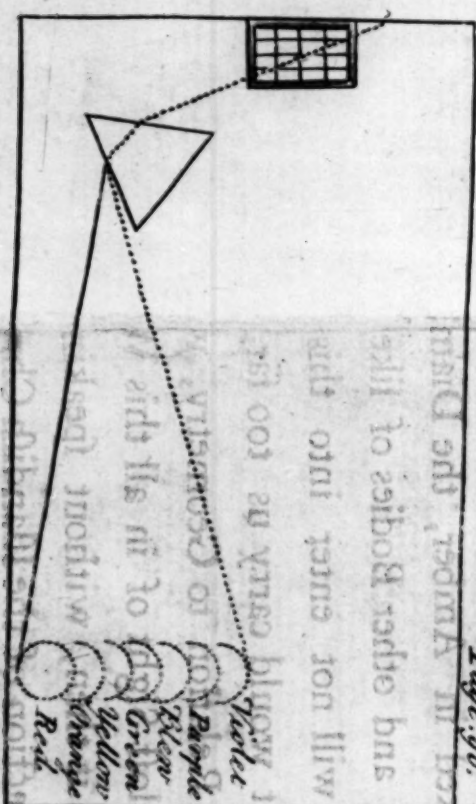
varied, at leaft fince they have been obferved, which is more than a hundred Years. In a Word, all thefe Inequalities are far fhort of thofe of the Moon ; not to mention her Rotation, which differs confiderably from what fome have thought they have perceived in the other Satellites.

After having run thro' all thefe different Motions, we can by no Means excufe ourfelves from fhewing their Caufe ; which is not fo obfcure as many People may have imagined. Take it in a few Words. The reciprocal Attraction of thefe Planets, occafioned by their Number and Proximity, is much fuperior to the Action of the Sun upon them. By this it is eafy to judge, that the Ring of Saturn muft extremely diforder the Satellites which make their Revolution round it, efpecially the fmalleft and moft excentrical of them. In like manner we may judge, that the Attraction of this Ring muft confiderably retard the Defcent of Bodies upon the Surface of Saturn. In fine, the Example of the Flux and Reflux of the Sea, will not fuffer us to doubt of this Truth. For it is a Confequence of all that was faid in Chap. XVIII.
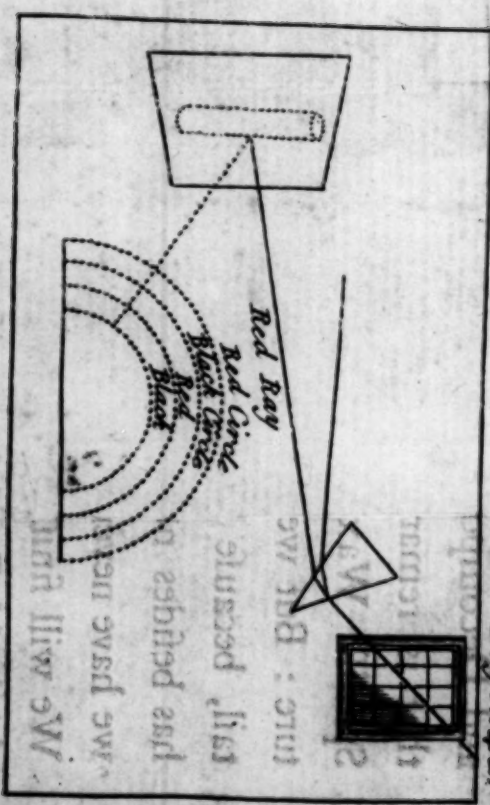
that

that the Gravity of the Center of the Earth towards the Moon is always the fame; whereas the Waters that happen to be between this Center and the Planet, are there attracted with more Velocity, than when the diurnal Rotation of the Earth has tranfported them to the Point diametrically oppofite.

This is what we had to fay concerning the principal Effects of the *Newtonian* Attraction, fuch as it was imagined by that famous Mathematician; by regarding it as the only Caufe of the Refraction of Light, and as the firft Spring of the Mechanifm of the Univerfe. In Quality of a Philofopher, it is true, he affigned to it an Empire in Nature yet much more extenfive, by reducing under its Laws all the Operations of Heat, the Compofition and Decompofition of Mixts, the Electricity that is remarked in Amber, the Diamond, Spanifh Wax, and other Bodies of like Nature : But we will not enter into this Detail, becaufe it would carry us too far, and has befides no Relation to Geometry, which we have never loft Sight of in all this Work. We will finifh it then, without fpeaking of the double Refraction of the Iflandifh Chryftal,

5

Place this Plate at the end of the Book.

Page.96.

Violet
Purple
Blue
Green
Yellow
Orange
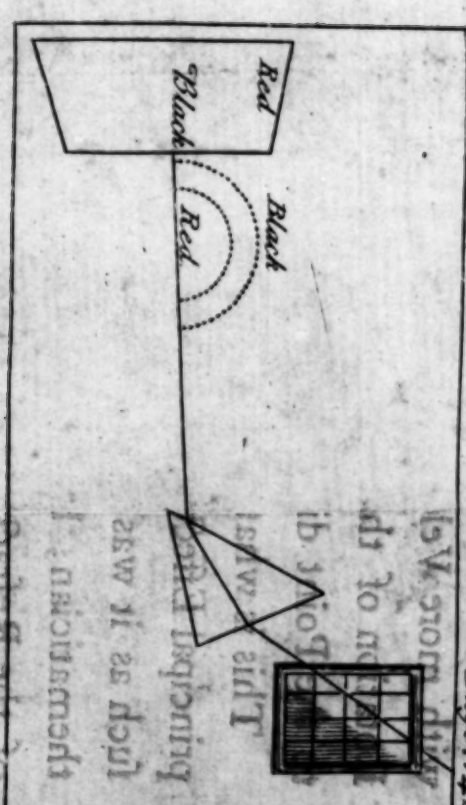Red

Page.142.

Red Ray
Red Circle
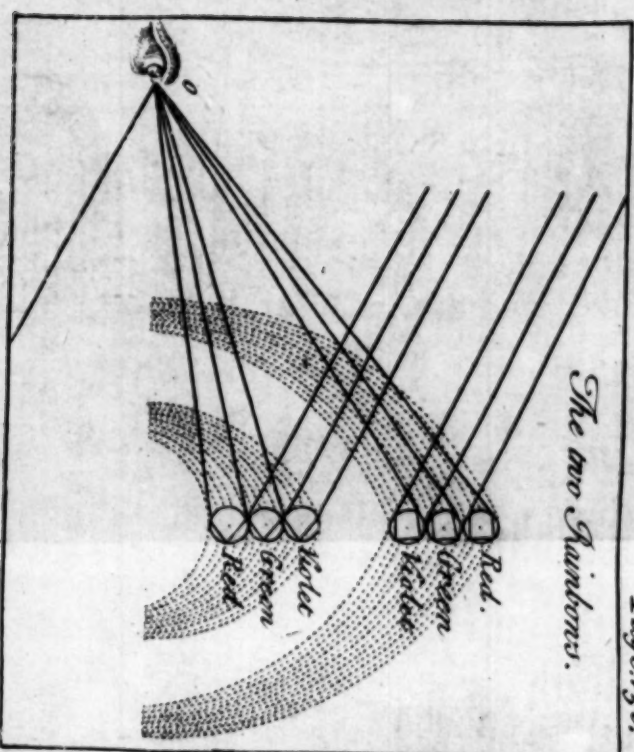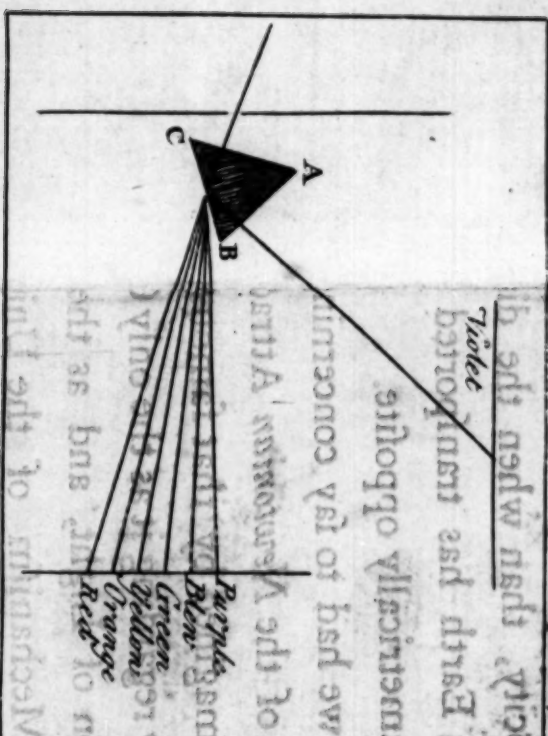
of the Diminution of the Denfity and Elafti-
city of the Air, of the Tenacity of vifcous
Mediums, in which any Body whatfoever
may move ; and many other fimilar Mat-
ters. It is for the fame Reafon that we have
but lightly touched on certain Things, fuch
as the Preceffion of the Equinoxes, and the
periodical Return of the Tides ; Phænomena,
in which there muft be yet fome other mix'd
Caufe, that has been hitherto unknown. For
if we are ignorant of what occafions the Equali-
ty of the Motion of Jupiter's equinoctial Points,
and of the Nodes of his Satellites, we are no lefs
ignorant why the Flux and Reflux of the
Sea follows rather the Mean, than the true
Motion of the Moon. At leaft we muft con-
fefs, that the Concurrence of the Sun's Ac-
tion with that of a Satellite, upon a principal
Planet in the Syzigiæ, or their Difference in
the Quadratures, cannot furnifh us with the
Reafon of thefe two Effects.

14 NO 63

F I N I S.

Explanation of the hard Words used in this Treatise.

A.

ANecdote, is a secret History, or private Memoirs.

Attraction is the Effect of a Power in Matter, by which all Bodies tend to one another, with a Force in Proportion to the Quantity of their Matter.

Atmosphere is all that Air that surrounds the Earth, which rises 50 Miles above its Surface, as appears by the Mercury in the Barometer.

Aries is the first of the 12 Signs in the Ecliptic, each containing 30 Degrees.

Area is a Space inclosed on any Superfice.

C.

CUBE is a solid Figure, in which all the Dimensions, Breadth, Height and Depth are equal, or a Number arising from its Square, multiplied by the Root, as 27 comes from 9 by 3.

Convex is the Outside of a curve Line, or Superfice.

Concave, the Inside thereof.

Cone is a solid Figure, wherein its circular Base tapers, till it come to a Point, as a Sugar Loaf.

Converge. Lines are said to converge, when they come nearer to one another the more they are continued, and do at last meet in a Point.

Catoptricks is a Science, in which the Laws of the Reflection of Rays are explained and demonstrated, as why an Object appears in one Part of a Looking-Glass, and not in another, &c.

Cataract is a Distemper in the Eyesight, arising from a thick Crust on the Pupil of the Eye.

Centri-

Centrifugal Force, is that whereby Bodies moving circularly, tend to go from the Center of the Motion called sometimes a projectile Force.

Centripetal is a Force whereby Bodies tend to the Center of this Earth, or any spherical Body by Attraction, called sometimes Gravity.

D.

Diverge. Lines are said to diverge, when coming from a Point, they go further from one another the longer they are continued.

Dead Force, is that which inclines Bodies to Motion, tho' there be none, as a Stone presses with a dead Force to the Center of the Earth.

Disc is that Part of a Globe that appears to our Eye, as in an Eclipse of the Sun the Moon covers a Part or the whole of its Disc.

E.

Ellipsis is such an oval Figure as would arise by cutting a Cone through its two Sides obliquely, such as that in our Tables that are near, but not quite round.

Equator is an imaginary Circle at equal Distance from the two Poles of the Earth, which if enlarged would reach to the equinoctial Line in the Heavens.

Ecliptic is a Circle cutting the Equator, with an Angle of 23 Deg. and 29 Min. through which the Sun seems to move in a Year.

F.

FOCUS is a burning Point near the middle of a Piece of Glass in the Form either of a Globe, where the Rays of Light would meet, or of an Egg, if its longest Diameter were directed to the Sun, it is applied to a Point in the Axis of the Section of a Cone.

G. *Group,*

G.

*G*ROUP, or Bundle, its applicable to a Pencil of Rays that come from the Sun, which may contain either the same or different sorts of Rays.

H.

*H*Emisphere is the half of a Globe, either of the Earth or Heavens, &c.

I.

*I*Ndefinite is that which, tho' it hath Limits, yet they cannot be conceived by us.

Inflection is bending, which the Rays of Light make in passing by the Edges of sharp Bodies.

L.

*L*IVING Force is that which actually produces some Motion.

Latitude is the Distance of a Place from the Equator in Degrees and Minutes.

Longitude is the Distance of the Meridian of a Place from that which is called the first Meridian, counted on the Equator in Degrees.

M.

*M*Icroscope, is an Instrument in which are two or more convex Glasses, through which an Object is greatly magnified.

Meridian, is an imaginary Circle passing through both Poles, which may be conceived either in the Heavens, or on the Earth; if it pass through our Place or over us, it is called our Meridian.

N.

*N*ODES are the two Points in which one great Circle cuts another, as the Orbit of the Moon cuts the Ecliptic in two Points, that are the Moon's Nodes.

O

*O*RBIT of the Moon is not the Circumference of her Disc, but the Circle her Center describes round the Earth, or rather the Ellipsis; Allowance being made by the Attraction of surrounding Bodies.

Oscillation is the same with Vibration, or swinging of a Pendulum, or any heavy Body, hung on a Point.

Opticks is the Doctrine and Vision in which the Parts of the Eye, their Use and Manner of seeing, is described

P.

*P*LANET is a dark Globular Body, revolving about the Sun, or some other Planet, which being illuminated by the Sun, appears luminous as the Planets Jupiter, Saturn, Mars, Venus, that appear like fixed Stars, but are not.

Plenum is a Space quite void of Matter.

Parallellogram is a Figure of four straight Sides parallel, and the two opposite Sides equal.

Polar Circles are small Circles, within 23 Deg. and ½ of each Pole.

Prism is a solid Figure, inclosed by parallel Planes, of the same Length, and is called either triangular or square, according as the two Ends are. In a triangular Prism of Glass the different Kinds of Rays are parted by their different Refractions.

Pores are small Spaces in Bodies thought to be void, or that do contain a fine Fluid.

R.

*R*Etina is a fine Net on the back Part of the Eye, on which the Images of Objects are painted.

Ray of Light is a most swift Motion of its Atoms from the Sun, tho' it comes also from some Flies, rotten Wood, dry'd Fish.

Refran-

Refrangibility is a certain Power, by which a Ray of Light is turned out of its Courſe paſſing from one Medium into another, as from Air to Glaſs or Water, which Power ariſes from ſome Quality in the Ray which denominates it either Red or Green, &c.

Ratio is the Proportion between one Number, ſuperfice, or Body and another ; two Ratio's are ſaid to be inverſe or reciprocal, when more gives leſs, or leſs gives more.

S.

SAtellite is a ſecondary Planet, revolving about a primary one, as thoſe of Jupiter, Saturn, and that of the Moon about our Earth.

Spheroid is an Egg-like Figure, in which one Diameter is longer than the other.

Square Number, is the Product of one Number multiplied by another, as 9 is the Square of 3, and 3 the Root of 9.

Solſtice is the fartheſt Point the Sun goes to from the Equator, either North or South.

Sine of an Angle or Arch, is a Line from the End of it perpendicular to the ½ Diameter.

T.

TRranſparent is that which admits the Light to paſs eaſily through it.

Teleſcope is an Inſtrument in which are two or more Glaſſes, of ſuch a Figure, that the Rays are brought thereby to our Eye, ſo as to ſee Objects far off diſtinctly, and as it were near us.

V.

VAcuum is a Space in which there is no Matter, either in the Pores of Bodies, or beyond the Limits of the World.

Z *Zenith*

ZEnith is the Point in the Heavens exactly over our Head, and Nadir the Point opposite to it.

Zodiac is a broad Circle in the Heavens, in which all the Planets move, being about 8 Deg. broad on each Side of the Ecliptic.

Zone is all that Space comprehended either between the Poles and Polar Circles, and is called the frigid Zone; or between the two Tropicks, which is called the torrid or burning Zone; or between the Tropicks and the polar Circles, and is called the temperate Zone.

THE END.

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